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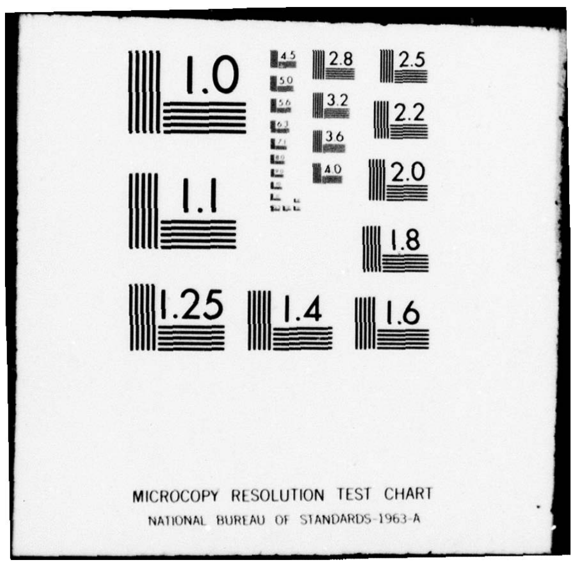
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MARINE CORPS COMMAND AND CONTROL FIBER OPTIC DATA BUS FEASIBILITY STUDY

A Schaefer

1 November 1978

Research and Development Report: 1 Oct 1977 - 30 Sept 1978

Prepared for
Chief of Naval Material

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NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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ADMINISTRATIVE INFORMATION

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SUMMARY

OBJECTIVE

Determine the feasibility of a fiber optic data bus structure for a tactical Marine Corps Command-Control System using typical MIFASS system requirements, existing data bus architectures and protocols, and state-of-the-art fiber optic components.

RESULTS

A system analysis showed that it is feasible to use a fiber optic data bus to interconnect the shelter equipments of a typical Marine Corps Command-Control System. A number of problems and developmental risk areas associated with the optimum system design were identified.

RECOMMENDATIONS

1. Design and build a demonstration fiber optic data bus to interconnect typical equipments used in a tactical Marine Corps Command-Control shelter in order to verify in the laboratory the conclusions of the system analysis.

2. Investigate the feasibility of a failsafe distributed control system for the fiber optic data bus system.

3. Conduct a configuration study to determine the best method of building up cable segments to compensate for cable length variations caused by the parallel nature of the multiple access star coupler architecture.

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I. EXECUTIVE SUMMARY

This report describes the NOSC FY78 effort to determine the feasibility of a fiber optics data bus structure for a typical Marine Corps Command-Control System. System analysis techniques were used to develop an optimum system design using typical MIFASS system requirements, existing data bus architectures and protocols, and state-of-the-art fiber optic components. The optimum system design was selected on the basis of the highest performance rating, the lowest differential cost, and low/moderate developmental risk. The salient characteristics of the selected fiber optic data bus system are:

- Lightweight single fiber technology
- State-of-the-art fiber optic star couplers
- Passive couplers, no repeaters, no serial elements
- High availability, survivability and flexibility
- Modularly expandable from the smallest to largest shelter
- Graceful transition from normal to backup operation
- Reduced cabling weight and volume contribute to ease of transportability
- EMI/EMP/TEMPEST – proof fiber optic cabling.

In order to reduce the moderate developmental risk associated with some of the state-of-the-art fiber optic components, it is recommended that additional efforts be initiated in FY79 in the following related areas.

- Design, build and test a demonstration fiber optic data bus interconnecting typical equipments used in a tactical Marine Corps Command-Control Shelter System using state-of-the-art fiber optic components, optimum configuration, controller scheme, and protocol developed from the FY78 and FY79 efforts.
- Investigate the feasibility of a failsafe distributed control system for the fiber optic data bus system.
- Conduct a configuration study to determine the optimum method of interconnecting the equipments in a non-sheltered configuration, the optimum location for the star coupler, and the best method of building-up cable segments to compensate for cable length variations caused by the parallel nature of the multiple access coupler architecture.

II. INTRODUCTION

The effort described in this report was carried out under the USMC Command-Control Technology Direct Development Funding Program (Task Area Plan No. ZF21-203-080). The FY78 effort was to determine the feasibility of a fiber optics data bus structure for a typical Marine Corps Command-Control System.

The approach employed system analysis techniques to develop an optimum system design based on typical requirements, existing data bus architectures and protocols, and state-of-the-art fiber optic components. The requirements of the Marine Integrated Fire and Air Support System (MIFASS) were selected as typical for Post–1980 USMC Command-Control Data Bus requirements. The analysis identified one candidate system as a clear choice in both performance and cost. The developmental risk areas associated with this design are identified and a demonstration fiber optic data bus system for FY79 is proposed.

III. REQUIREMENTS

A. MIFASS DATA BUS DESCRIPTION

The requirements for the fiber optic data bus were gleaned from the overall MIFASS contract specification for the Engineering Development Model (EDM) dated 1 August 1977. MIFASS is a command-control system designed to optimize the utilization of fire and air support assets by providing near real-time information to commanders to facilitate faster and better fire support decisions. A block diagram of the MIFASS Control Center is shown in Figure 1. Three data buses are identified in this diagram.

1. Internal center data bus provides the data exchange between the microcomputers, dynamic situation displays and associated peripherals such as mass memories, mass storage devices, and printers.

2. Trunk I/O data bus provides the interface between the microcomputers and the data buffers from/to arms observers and fire units such as TACFIRE, PLRS, ULMS, etc.

3. DCT NET data bus provides the interface between the microcomputers and the net buffers from/to the remote and local digital communications terminals (DCT).

The number of equipments which is assigned to each data bus varies with the division, regiment, or battalion size center. Table 1 lists the equipments housed within rigid shelters. Table 2 lists equipments for unsheltered centers. Both sheltered and unsheltered centers shall make use of fiber optic cabling. The contractor has the design option of partially or fully combining buses A, B, and C. For this analysis, buses A, B, and C will be considered as a single bus, due to the relatively small number of users assigned to each.

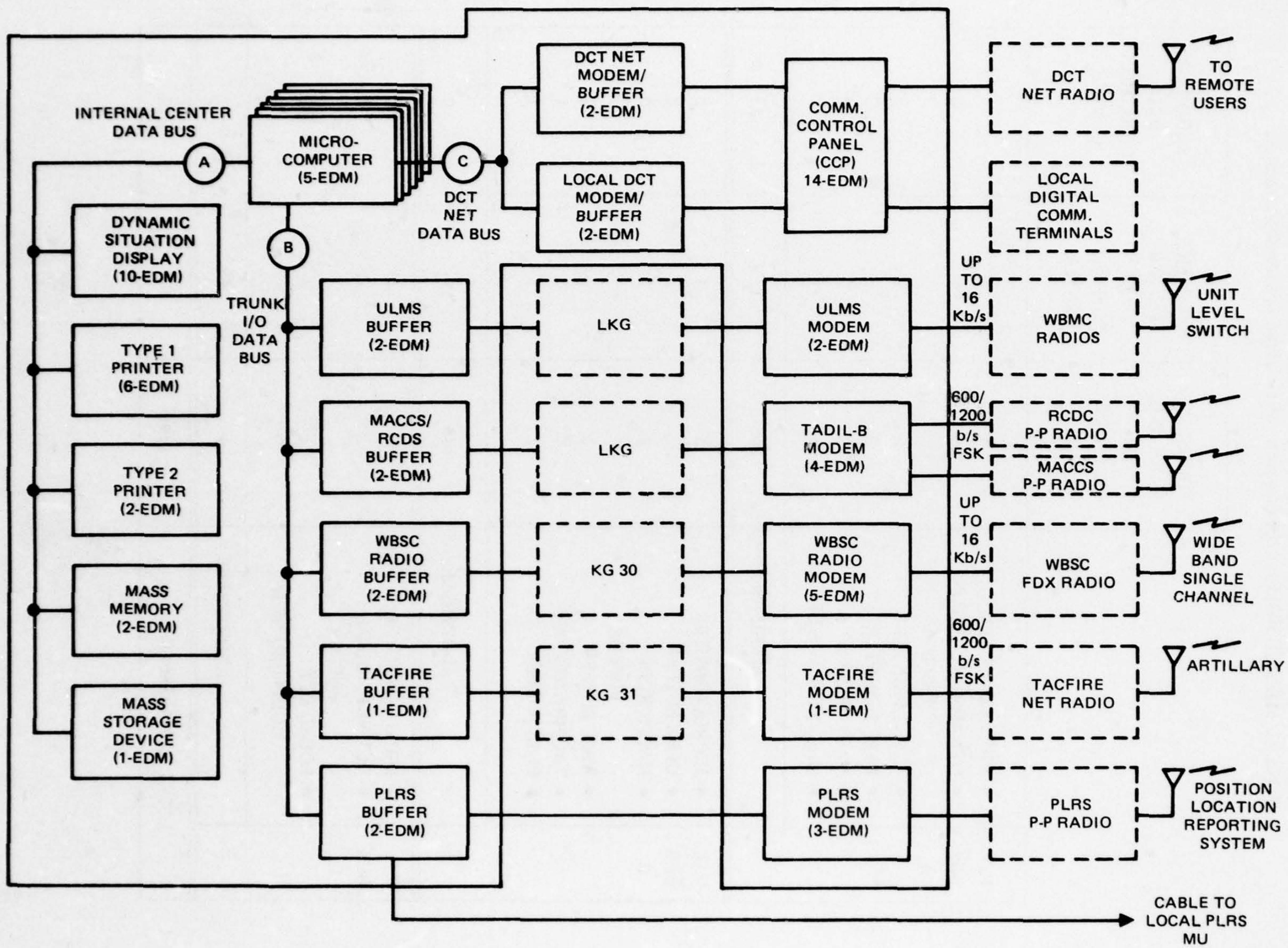


Figure 1. MIFASS control center, block diagram.

Table 1. MIFASS EDM baseline system, shelterized center equipments.

		DIVISION FIRE AND AIR SUPPORT CENTER	REGIMENT FIRE AND AIR SUPPORT CENTER	REGIMENT FIRE DIRECTION CENTER
F.O. BUS A	• MICROCOMPUTER	5	4	3
	• DYNAMIC SITUATION DISPLAY	10	6	3
	• TYPE 1 PRINTER	6	2	2
	• TYPE 2 PRINTER	2	2	2
	• MASS MEMORY	2	2	2
	• MASS STORAGE DEVICE	1	1	1
	ADDRESSEES =	26	17	13
F.O. BUS B	• MICROCOMPUTER	5	4	3
	• ULMS BUFFER	2	2	2
	• MACCS/RCDC BUFFER	2	2	0
	• WBSC BUFFER	2	2	2
	• TACFIRE BUFFER	1	1	1
	• PLRS BUFFER	2	1	1
	ADDRESSEES =	14	12	9
F.O. BUS C	• MICROCOMPUTER	5	4	3
	• DCT NET MODEM/ BUFFER	2	2	2
	• LOCAL DCT MODEM/BUFFER	2	2	2
	ADDRESSEES =	9	8	7
TOTAL ADDRESSEES		49	37	29

Table 2. MIFASS EDM baseline system, unsheltered center equipments.

		MARINE AMPHIBIOUS FORCE, FIRE AND AIR SUPPORT SECTION	BATTALION FIRE & AIR SUPPORT CENTER	BATTALION FIRE DIRECTION CENTER
F.O. BUS A	• MICROCOMPUTER	3	2	2
	• DYNAMIC SITUATION DISPLAY	4	2	2
	• TYPE 1 PRINTER	3	2	2
	• TYPE 2 PRINTER	3	0	2
	• MASS MEMORY	1	2	2
	• MASS STORAGE DEVICE	0	0	0
	ADDRESSEES =	14	8	10
F.O. BUS B	• MICROCOMPUTER	3	2	2
	• ULMS BUFFER	1	2	2
	• MACCS/RCDC BUFFER	0	0	0
	• WBSC BUFFER	1	2	2
	• TACFIRE BUFFER	0	0	2
	• PLRS BUFFER	0	0	0
	ADDRESSEES =	5	6	8
F.O. BUS C	• MICROCOMPUTER	3	2	2
	• DCT NET MODEM/BUFFER	2	2	2
	• LOCAL DCT MODEM/BUFFER	2	2	2
	ADDRESSEES =	7	6	6
TOTAL ADDRESSEES		26	20	24

B. GENERAL DATA BUS REQUIREMENTS

The following data bus requirements for a typical Marine Corps Command-Control System will be used as a baseline for the fiber optic data bus analysis.

1. All data buses shall be entirely fiber optic cables.

2. Data shall be serial, with timing and control signals on the same line as the data.

3. The design shall be modularly expandable from the minimum size center (20 addressees) to the maximum size center (49 addressees) and shall accommodate up to 256 addressees.

4. The data bus shall operate at a transmission rate up to 10 Mb/s.

5. The data rate requirements of various addressees shall range from very slow (600 b/s to very high speed (400 K b/s). An estimated distribution of typical data rates among addressees is given in Section V, paragraph B of this report.

6. Sheltered systems shall be housed in two 8 X 8 X 10 ft rigid shelters for smaller centers and two 8 X 8 X 20 ft rigid shelters for larger centers.

7. It shall be possible to remove equipments from a shelter to be reconnected with a second set of fiber optic cables for operation externally as an unsheltered center.

8. The system design shall allow up to 50 m separation of the shelters in normal operation.

9. The system design shall allow equipments to be located between one and 20 m from each other for sheltered and unsheltered configurations. Maximum distance a signal may have to be driven is:

Division center	200 m
Regimental center	75 m
Smaller centers	50 m

10. Echeloning of centers during operation shall be required. This shall be accomplished by functionally reconfiguring the center so that all functions are performed in one shelter. The other shelter shall be shut down, packed for transport, transported to a new location, unpacked, and set up for operation. All functions shall be transferred to the shelter at the new location. The shelter at the old location shall be shut down, packed, transported, unpacked, and set up for operation. The center shall then be reconfigured to allocate functions to both centers for normal operation.

11. Availability shall be as follows:

Unit Availability	>0.999
Center Availability	>0.990

12. The reliability of the cable assembly shall be $\geqslant$50,000 hours MTBF.

13. Maintainability shall be as follows:

Unit Maintainability	$\leqslant$ 30 min MTTR
Center Maintainability	15 min Mean Down Time
	30 min Max

IV. APPLICABLE STATE-OF-THE-ART FIBER OPTIC COMPONENTS

A. BUS SYSTEMS

Although the basic technology is available, there are presently no operational fiber optic data buses in existence. A number of developmental fiber optic data bus systems have been built as demonstration units. These couple four through eight users (equipments) at up to a 10 Mb/s data rate. The MIFASS data bus requires interconnection of up to 256 users.

The concepts of the design of a fiber optic bus system are well known. It is similar to the design of a point-to-point link in that a link optical power budget and a link rise time budget are initially required. These power budgets determine the appropriate sources, fiber, and detector types required to meet the system performance. The power budget consists of calculations of worst case optical power losses along the highest and lowest loss paths. The minimum received signal level (sensitivity) determines what combinations of bit rate and error rates are attainable with a particular bus design. Each optical receiver must be able to operate at all signal levels encountered from the highest to the lowest loss paths. The difference between the losses of the highest loss path and the lowest loss path, expressed in decibels (dB), is known as the optical signal range. The optical receiver sensitivity and the optical signal range required are important parameters associated with initial fiber optic bus design.

B. MULTIPLE ACCESS COUPLERS

1. General

In order to implement a fiber optic data bus design, some type of multiple access coupler is required. These couplers include T-couplers, transmissive star couplers, reflective star couplers and bifurcation devices. Active T and star couplers with built-in electrical repeaters add to the variety of couplers available. In all cases, these couplers are developmental. No off-the-shelf units are available. The selection of couplers is further complicated because each manufacturer specifies his coupler parameters in a different way so that comparison and evaluation are difficult.

2. T-Couplers

T-couplers have been under development for about five years. The first units were rather complex internally and had large excess losses. Excess losses include internal coupler losses due to reflection, scattering, and absorption of the optical signal. Presently, most

T-couplers are being fabricated by using heat and pressure to fuse two fibers. Any optical power division from 1:1 to 10:1 can be obtained by using this method of fabrication. Excess loss should ultimately be much less than 1 dB compared to the 1 to 2 dB presently obtained. A substantial loss in each T-coupler is the connector loss of 1 dB for single fiber connectors and 3 dB for bundle fiber connectors. In the multidrop bus configuration, the T-coupler has been shown to be limited to less than 15 terminals due to these losses. For this reason, it is doubtful that it can be used for the Marine Corps Command-Control shelter application.

A bifurcation device, which is a variation of the T-coupler, is required where the fiber optic transmitter and receiver must both access a single fiber cable. This device is also called a directional coupler by some manufacturers and has about the same losses as the T-coupler. ITT Electro-Optical Products Division and Spectronics, Incorporated presently supply developmental units at prices ranging from $500 to $1,500.

3. Star Couplers

Figure 2 shows a much enlarged functional representation of the two types presently being developed by a number of manufacturers. In the reflective star coupler, light signals entering any one of the fibers are diffused in the mixing block and after reflecting off the mirrored surface, equally illuminate all the output fibers. The transmissive star coupler is similar except that a mirror surface is not used. The optical signal passes directly through the mixing block and illuminates all the output fibers at the opposite end of the coupler.

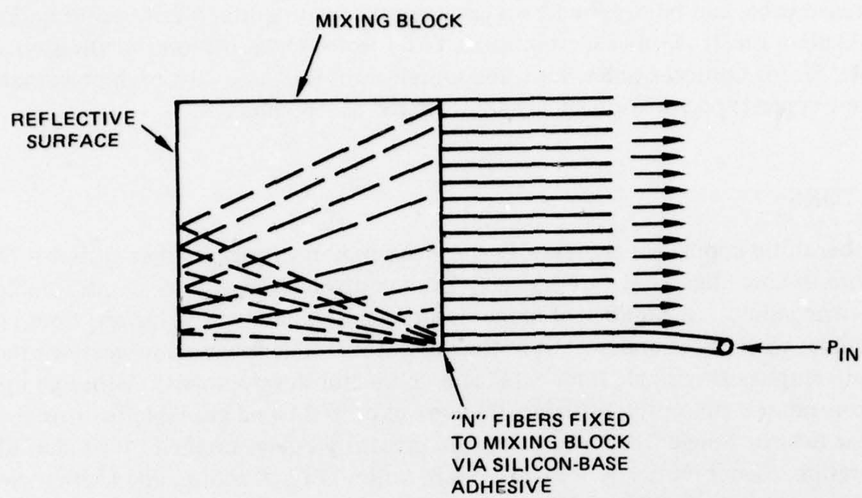
The reflective and transmissive star couplers have rather large excess losses (5 to 7 dB) and port-to-port optical output variations (±2 dB). These parameters are the most important in judging the quality of the coupler. Some manufacturers are presently fabricating the transmissive star coupler with a simple heat and pressure method of fusing up to 19 single fibers. This method of fabrication reportedly produces excess losses of only 1.5 dB and port-to-port variations of ±1 dB. Connectors required with these couplers account for additional losses of 1 dB for each single fiber connector and 3 dB for each bundle fiber connector. Consistent production of couplers with these losses means a viable component for use in the Marine Corps Command-Control shelter application. ITT Electro-Optical Products Division and Spectronics, Incorporated presently supply developmental multiple access optical couplers at prices ranging from $1,000 to $7,500 depending on the number of access ports. (See Appendix A for vendor specification sheets.)

C. FIBER OPTIC CABLE

The choice between single and bundle fiber cable is an important one for this application. A bundle fiber cable is one where many fibers are grouped together and are illuminated by one light source. A single multimode fiber cable is one where each fiber is illuminated by a separate light source. One to six fibers are usually contained within the cable.

Developments in single fiber cable technology have been moving rapidly within the past year. The trend for military applications has also been going in that direction. The Marine Corps Command-Control shelter bus application requirement for a small diameter, strong, flexible, lightweight cable can presently be met by a number of manufacturers. These

REFLECTIVE STAR COUPLER



TRANSMISSIVE STAR COUPLER

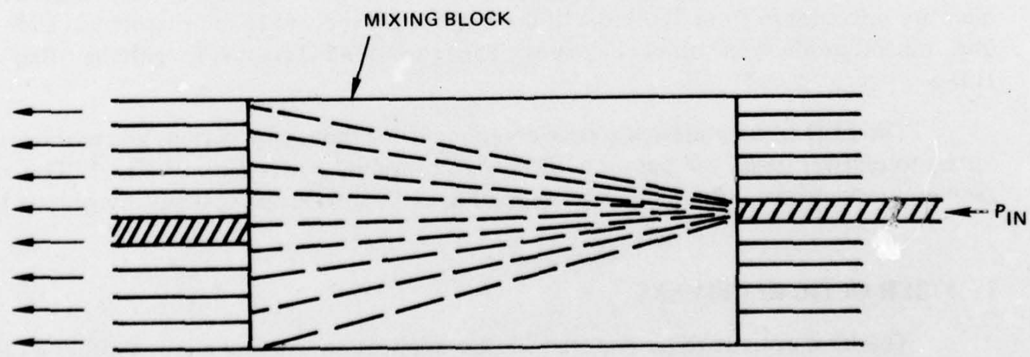


Figure 2. Multiple access star couplers.

cables consist of a plastic clad silica, glass step index, or glass graded index fiber with a number of Kevlar strength members. For environmental reasons glass cladding is preferred over the plastic cladding. The short transmitter to receiver links and low data rate of 10 Mb/s will permit use of low loss step index fiber since pulse spreading will not be a problem. The single fiber strengthened cable can be supplied by a large number of manufacturers including Valtec Corporation, Galileo Electro-Optics Corporation, ITT Electro-Optical Products Division, Times Wire and Cable, Siecor Optical Cables, Inc., and Optelecom, Inc., at a cost of approximately $1 per foot. A few typical specification sheets are included as Appendix A.

D. CONNECTORS

The fiber optic connector is presently the weak link in the single fiber system. The problem of core-to-core alignment varies greatly from controlled laboratory conditions to a tactical field environment. A number of manufacturers have demonstrated single fiber connectors and splices with losses under 1 dB in the laboratory. The telecommunications industry and military are emphasizing single fiber cable and connector development. Although militarized connectors are not presently available, they are expected to be available for this application in the near future. Single fiber connectors are presently being supplied by Galileo Electro-Optics Corporation, Siecor Optical Cable Inc., T&B/Ansley, ITT, Cannon, and Cablewave Systems Inc., at costs from $100 to $500.

E. TRANSMITTERS

The digital fiber optic transmitter required for this application may use either a Light Emitting Diode (LED) or an Injection Laser Diode (ILD). The ILD has a higher output power (5 to 10 mW) than the LED (0.01 to 0.02 mW) and can couple much more optical power into the single fiber than the LED. The ILD has a narrower optical spectral width (4 nm vs 50 nm) than the LED and therefore reduces the problems caused by material dispersion. There are some disadvantages associated with the use of ILDs. ILDs are much more temperature sensitive than LEDs. The operating life of ILDs is less than that of LEDs (10^4 vs 10^5), but the gap is being closed rapidly. The cost of ILDs is presently very high. Low quantity prices range from $100 to $1,000, but this is expected to fall sharply as yields improve and production volume increases. The range of LED costs is roughly half that of ILDs.

The LED is the preferred source component for those applications where the transmitter to receiver losses will permit a lower source module power output. The LED is less temperature sensitive, has a greater operating life and a substantial cost advantage over ILDs.

F. FIBER OPTIC RECEIVERS

The fiber optic receiver required for this application will make use of either a PIN photodiode or an avalanche photodiode (APD). The APD exhibits an internal gain and is designed for use in applications requiring greater sensitivity. Use of an APD photodiode can add 15-17 dB of additional sensitivity to the fiber optic receiver compared to use of a PIN

photodiode. The disadvantages associated with use of the APD include the necessity of a large bias voltage, pronounced temperature sensitivity, and higher cost ($200 to $500 vs $10 to $50 for the PIN photodiode). For these reasons, the PIN photodiode is preferred over the APD photodiode in those applications where the optical receiver sensitivity permits.

V. DATA BUS SPECIFICATIONS AND ARCHITECTURES

A. GENERAL

In order to avoid generation of a completely new data bus concept, maximum use was made of existing standard bus specifications. A number of specifications were identified and reviewed for possible application to the Marine Corps Command-Control data bus design. The following specifications were included.

1. MIL-STD-1553A

This is a standard for a serial digital metallic data bus as used aboard aircraft. The bus operates asynchronously in the Command Response Mode at a transmission rate of 1 Mb/s. Manchester II encoded data is used. The standard defines the word length, message format, controller protocols, and bus interfaces. This bus standard has been specified for use on the F16 and F18 aircraft and has definite potential application to the Marine Corps Command-Control data bus design.

2. MIL-STD-1553FO

This standard, as the title implies, is a fiber optics version of MIL-STD-1553A and is presently being finalized. When completed, it will be assigned a new number. It is very similar to MIL-STD-1553A with appropriate changes to accommodate fiber optics. The type of fiber cable is not defined in the standard nor are the access couplers defined further than "STAR" and "TEE." This is the only known fiber optic bus standard and will be considered for use in the Marine Corps Command-Control data bus design.

3. NTS Interface Standard

This serial digital metallic data bus standard for shipboard use is presently being finalized. It is very similar to MIL-STD-1553A except the transmission rate is 100 Kb/s. When completed, this standard will be used on the Navy's ACCS (Advanced Communication Control System). This standard offers nothing new over MIL-STD-1553A.

4. MIL-G-85013

This is a serial digital metallic data bus standard for use aboard aircraft. The bus operates asynchronously in the Command-Response Mode similar to MIL-STD-1553 and

also in the Polled-Contention Mode. Data transmission on the bus is 1 Mb/s over a shielded twisted wire pair. Word lengths, message formats, controller protocols, and bus interfaces are defined in the specification for both modes of operation. This standard is scheduled for use on a number of aircraft systems. The Polled-Contention Mode of operation has potential application to the Marine Corps Command-Control data bus design.

5. Shipboard Data Multiplex System (SDMS)

This is a multi-channel, duplex, serial, asynchronous, multi-redundant, modular, data bus system for use on small to large ships. Four 1.2 Mb/s data channels plus a 1.2 Mb/s control channel modulate carriers which are frequency division multiplexed for transmission by five coaxial cable primary buses. Five carriers between 40 and 80 MHz are utilized. Total peak ("burst") data rate is 24 Mb/s with actual data transfer ("throughput") rates up to about 11 Mb/s. Coaxial cable lengths of up to 1500 ft per channel (transformer-coupled) are allowable for the main bus.

The architecture of this system is most cost-effective where the cable runs are long and the equipments to be interconnected are well spread out. In a field shelter application, the size and weight of the multiplexers cancel out any savings due to use of fiber optic cabling and bus techniques. In the system analysis to follow, one of the candidate bus systems will make extensive use of multiplexing.

6. IEEE-STD-488 Bus

This is a digital interface standard for the transfer of digital data among programmable instruments and system components. The data bus contains 8 signal lines that operate asynchronously in bit-parallel, byte-serial format at 1 Mb/s maximum data rate. The maximum number of devices that can be connected on a line is 15 and the maximum length of the transmission path is 20 m. This specification has primary application to automatic testing systems using programmable instruments.

7. IEEE-STD-583

This is a digital interface standard for a range of modular instrumentation capable of interfacing transducers and other devices to digital controllers for data and control. The bus consists of up to 86 lines including power arranged in a standard enclosure containing functional and interface modules for connection to computers, peripherals, and other users. Many of these "crates" can be stacked into a parallel or serial "highway." This specification has primary application to industrial control.

B. THROUGHPUT ANALYSIS

1. General

The Command-Response Mode of MIL-STD-1553A and the Polled-Contention Mode of MIL-G-85013 are the primary candidates for the Marine Corps Shelter Command-Control data bus protocol. The initial check to be made in regard to these data transfer schemes is an information throughput analysis. This analysis will determine if the allowable bus transmission data rate is sufficient to permit all terminals to be serviced without any loss of data. The throughput analysis must consider protocol overhead bits and terminal response times in addition to information data words to be transferred.

In order to perform the throughput analysis, an estimate must be made of the expected data transfer rates required of all 256 eventual users. Some of these data rates are available and some can only be determined after the detailed system design is complete. The data on the trunk I/O data bus buffers from the remote radios range from 600/1200 b/s to 16 Kb/s according to the MIFASS specification. The data rate on the internal center data bus between microcomputers, printers, and display units will be at a maximum of 9600 b/s. The microcomputer to mass memory links could vary greatly in required data transfer rates depending on the system design. This link may require a very high burst data transfer rate which could overload the main bus operating at 10 Mb/s. If this occurs, the microcomputer to mass memory link may have to be a separate bus. For the throughput analysis we shall consider the required microcomputer to memory transfer rate and microcomputer to microcomputer transfer rate to be a constant 400 Kb/s. The distribution of data rates among addressees is estimated to be as follows:

	Qty	Info Rate Requirement	Total Info Transfer Bit Rate Required
Comm Buffers	100	600/1200 b/s	0.12 Mb/s
	44	16 Kb/s	0.70 Mb/s
Display, printers	100	9.6 Kb/s	0.96 Mb/s
Microcomputer, Mass memory	12	400 Kb/s	4.80 Mb/s
Total	256 Addressees		6.58 Mb/s

The total required information bit rate of 6.58 Mb/s allows a margin of about 1/3 of the 10 Mb/s bus transmission rate for overhead. This should be sufficient for both MIL-STD-1553A and MIL-G-85013 protocols. It is worth repeating here that these estimated transmission rates are for the ultimate number of 256 addressees. For the Engineering Developmental Model the quantities for the largest size center are as follows:

	Qty	Info Rate Requirement	Total Required Info Bit Rate
Comm Buffers	7	1200 b/s	8.4 Kb/s
	6	16 Kb/s	96.0 Kb/s
Display, printers	18	9.6 Kb/s	172.8 Kb/s

	Qty	Info Rate Requirement	Total Required Info Bit Rate
Microcomputer, Mass memory	8	400 Kb/s	3200.0 Kb/s
Total	39 Addressees		3.48 Mb/s

The total required information bit rate of 3.48 Mb/s for the engineering developmental model allows a margin of about 2/3 of the 10 Mb/s bus transmission rate for overhead.

2. COMMAND-RESPONSE THROUGHPUT ANALYSIS

The terminal-to-terminal data interchange for the Command-Response Mode of MIL-STD-1553A is shown in Figure 3. For the throughput analysis, a data bus transmission rate of 10 Mb/s per MIL-STD-1553A is assumed. In addition, a maximum of 32 data words are transferred per message block. A worst case condition was assumed in that continuous operation of all 256 terminals at their individual bit rates would result in the maximum bus load.

- Time To Service 1 Terminal:

2 command words, 20 bits	@	0.1 μsec each =	4 μsec
32 data words, 20 bits	@	0.1 μsec each =	64 μsec
2 status words, 20 bits	@	0.1 μsec each =	4 μsec
3 terminal/controller response times	@	0.5 μsec each =	1.5 μsec
			73.5 μsec

- Time to Service 256 Terminals

  256 X 73.5 μsec = 0.0188 sec

- Times/Second Each Terminal is Serviced

$$\frac{1}{0.0188} = 53.15$$

- Number of Information Bits Transferred Per Second Per Terminal:

  16 X 32 X 53 = 27,136 bits/sec

- Efficiency of Data Transfer

$$\frac{\text{information bits per second}}{\text{total bit periods per second}} = \frac{27{,}136 \times 256}{10{,}000{,}000} = 70\%$$

A 70% efficiency means that up to 30% of the total bit periods are used for overhead.

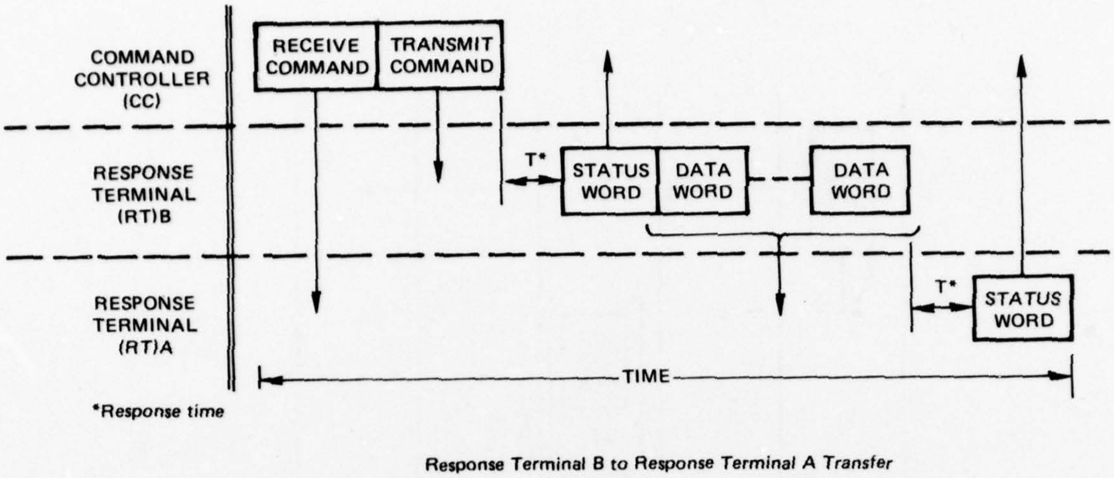


Figure 3. Message sequence for command-response configuration.

If some terminals do not require a full 32 words of data to be transferred because of their slow individual operating times or non-continuous operation, other terminals which do require it may be serviced at a more rapid rate. The bus should not be overloaded as long as the average terminal transmission rate is below 27,136 bits per second. For the equipment distribution assumed in paragraph V B1, the average terminal transmission rate is 25,703 bits/sec. Therefore, the Command-Response Mode of operation of MIL-STD-1553A can be used to service the 256 terminals at a 10 Mb/s transmission rate. For the Engineering Developmental Model, which requires only 15% of maximum capacity, the margin is very large.

3. POLLED-CONTENTION THROUGHPUT ANALYSIS

The terminal-to-terminal data interchange for the Polled-Contention Mode of MIL-G-85013 is shown in Figure 4. The same assumptions as in the previous Command-Response Analysis are used. That is, 10 Mb/s transmission rate, 32 data words transferred per message block, and continuous operation of all 256 terminals.

- <u>Time To Service 1 Terminal:</u>

1 bus offer word, 20 bits @ 0.1 μsec	= 2 μsec
1 message available word	= 2 μsec
1 message request word	= 2 μsec
32 data words @ 2 μsec each	= 64 μsec
3 terminal/controller response Times @ 0.5 μsec each	= 1.5 μsec
	71.5 μsec

This is a very slight improvement on the Command-Response Mode. No further calculations are required since there would be very little difference in the two modes as far as ability to transmit the required data. There may be other reasons for selecting one mode over the other. This will be discussed later in the report.

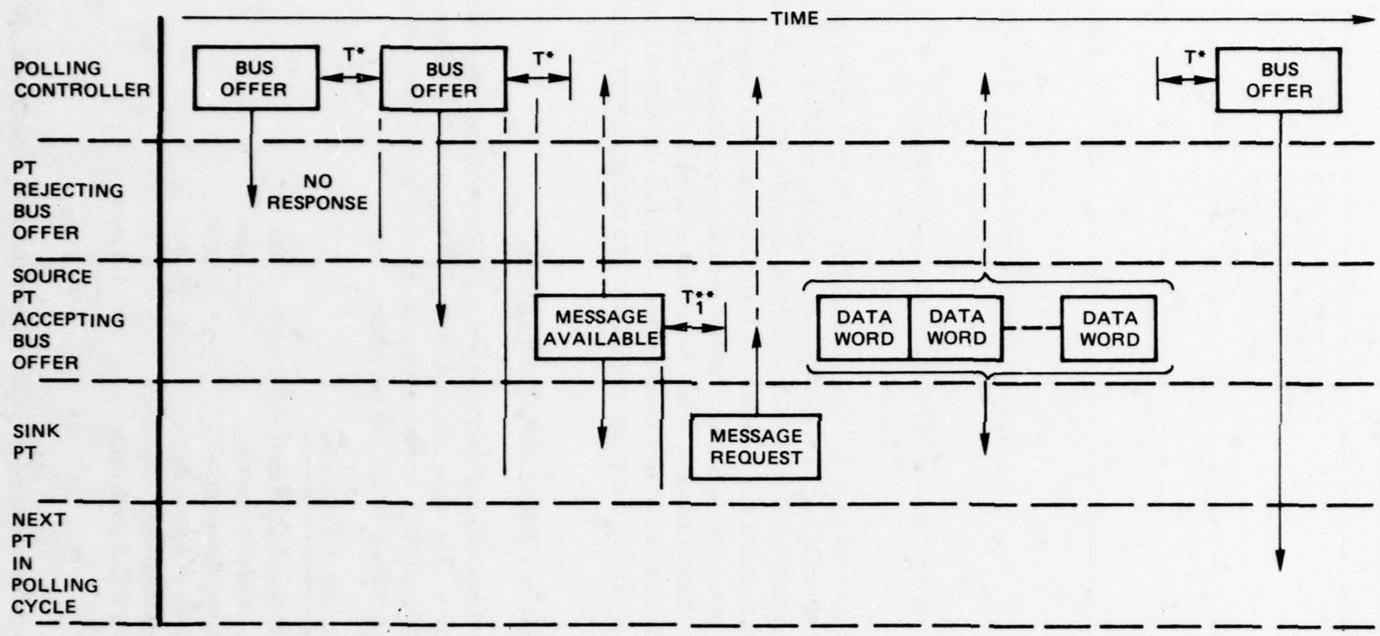


Figure 4. Message sequence for polled-contention configuration.

VI. SYSTEM ANALYSIS METHODOLOGY

A. DESCRIPTION

This section describes the system analysis methodology used to develop an optimum data bus system design for a typical Marine Corps Command-Control Center for the post-1980 era. The procedure used is listed here.

1. Generate typical command-control data bus requirements making maximum use of the MIFASS specification as a guideline.

2. Investigate existing data bus specifications and architectures for application to this fiber optics data bus design. Perform a system information throughput capacity analysis to determine if the information to be transferred plus the overhead data can be accommodated with the maximum bus data rate being considered.

3. Identify present state-of-the-art fiber optic data bus systems and components which have applicability to the Marine Corps Command-Control data bus.

4. Synthesize a number of alternate candidate bus configurations including multi-drop, ring, and tree. In addition, make use of active and passive star and T-couplers, single and bundle fiber technology, LED and laser sources, PIN and APD detectors, and multiplexing to satisfy the typical requirements which were generated above.

5. Delineate performance advantages and disadvantages for each candidate system. Eliminate from further consideration all candidate systems but the most promising.

6. Identify a number of performance evaluation criteria which are important for the Marine Corps Command-Control data bus system and which will help in the selection of one candidate system over another.

7. Subject each remaining candidate bus system to a performance analysis by determining how well each system meets the performance evaluation criteria. This step identifies the leading candidate system in the area of performance.

8. Estimate the cost of each of the alternate candidate systems and compare with the results of the performance analysis. Determine by subjective analysis the optimum system based on performance and cost.

9. Reevaluate the selected system to ensure it meets the original requirements. Determine if minor changes to the selected system will improve its overall performance/cost effectiveness.

10. Identify the developmental risk areas associated with the selected fiber optic data bus system and its components.

B. EVALUATION CRITERIA

The evaluation criteria discussed below have been selected as most important for the Marine Corps Command-Control shelter data bus application.

1. **Reliability, Maintainability, Availability**

The reliable performance of the system is of primary importance. The candidate fiber optic bus system having the best reliability, maintainability, and availability will be characterized by distributed control, design simplicity, fewest serial elements, no single point of failure, etc.

2. **Weight**

The reduction in weight of the shelter will make it more easily transportable and more rapidly deployable. A fiber optic data bus can substantially reduce the weight of the data cable required for the shelter.

3. **Volume**

The savings in space within the shelter will initially allow easier cable installation and thereafter permit personnel to perform their tasks more efficiently. The diameter of present bundle fiber optic cable is equal to or less than that of an equivalent use of coaxial cable. Single fiber technology promises to reduce the cable volume further.

4. **Graceful Degradation**

The ability of the system to smoothly and incrementally transit from normal to backup operation necessitated by component failure, battle damage, or echeloning is essential.

5. **Survivability**

The fiber optic bus could be run redundantly via alternate paths incurring only a small size and weight penalty. Damage to one bus would permit full operation of the command shelter to continue uninterrupted. A distributed bus control scheme would also contribute to increased survivability.

6. **Flexibility**

The fiber optic data bus system should have the ability for potential growth to accommodate increased capacity requirements by the addition of modular assemblies. It should also be built in a modularly expandable fashion so that the requirement of the smallest to the largest shelter can be accommodated.

7. **Primary Power**

Fiber optic transmitter and receiver modules have the potential to require less electrical power to operate than equivalent coaxial cable drivers and receivers. In the shelter application, this means savings in power generating equipment and/or battery backup system.

8. Transmitter to Receiver Optical Losses

The best architectural configuration on the bus design will result in the smallest transmitter to receiver path optical power loss. The larger the magnitude of the received optical signal and the smaller the required receiver dynamic range, the simpler the fiber optic receiver design becomes. The optical power margin of the received signal is significant in determining the bit error rate of the system. The transmitter to receiver optical losses, therefore, are an important consideration in the evaluation of alternate candidate bus designs.

9. Additional Criteria

In addition to those delineated above, there are a number of important characteristics which apply equally to all candidate fiber optic bus system designs and therefore will not help in the selection of one candidate system over another. Those characteristics are listed below.

a. tempest secure communications

b. EMI/EMP immunity

c. crosstalk isolation

d. wide signal bandwidth

e. corrosion resistance

f. electrical isolation

g. contact discontinuity

h. short circuit immunity

i. fire hazard immunity

j. high temperature tolerance

VII. ALTERNATIVE FIBER OPTIC DATA BUS CONFIGURATIONS

A. ASSUMPTIONS

The following assumptions have been made in order to establish a baseline for a preliminary evaluation of the alternate fiber optic bus configurations which follow.

1. There will be only a single data bus for each center.

2. All data cables are to be fiber optic from user-to-user.

3. A maximum of 256 addressees is required on the bus, expandable in groups of 8, 16 or 32.

4. Fiber optic multiple access couplers are preferred to be Passive "T" and "STAR" type couplers.

5. Preferred fiber optic component choices are to be

- LED source
- PIN detector
- single fiber technology, and
- star coupler

6. Star coupler state-of-the-art parameters (worst case):

	Bundle Fiber Coupler	Single Fiber Coupler
o excess loss	3 dB	7 dB
o port-to-port variation	3 dB	3 dB

7. Optical power division for uniform star coupler:

o 5- and 6-port	-7 dB
o 9-port	-9 dB
o 10-port	-10 dB
o 33-port	-15 dB

8. T-coupler state-of-the-art parameters: (single fiber technology)

o excess loss	1 dB
o port-to-port variation	1 dB
o power division	Normally -3 dB but may vary up to -10 dB

9. Optical power coupled into fiber:

- LED to single fiber -10 dBm
  (assuming low loss, glass core-glass clad step index fiber)
- LED to bundle fiber -3 dBm
  (assuming high loss, high numerical aperture, glass core-glass clad bundle fiber)
- ILD to single fiber +5 dBm
  (assuming injection laser diode to same single fiber type above)

10. Connector losses:

o single fiber	1 dB
o bundle fiber	3 dB

11. In estimating the amount of fiber cable required for a particular configuration, an average of 20 m per user will be used.

For attenuation losses, the following apply:

- Single Fiber Cable

  Assuming a low loss, glass core-glass clad step index fiber, 200 m maximum length @ 20 dB/km = 4 dB loss.

  This 4-dB fiber attenuation loss will be considered in calculating the optical signal range of each candidate configuration in addition to the transmitter-to-receiver path loss.

- Bundle Fiber Cable

  Assuming a high loss, high numerical aperture, glass core-glass clad bundle fiber, 200 m maximum length @ 200 dB/km = 40 dB loss.

  This cable attenuation loss must be considered in calculating the optical signal range of each receiver in addition to the transmitter-to-receiver path loss. The magnitude of 40 dB essentially eliminates bundle fiber cable as a usable alternative for this application.

12. Fiber Optic Receiver Design Requirements:

- Sensitivity

  (Digital receiver, 10 Mb/s, BER $\leqslant 10^{-10}$) using:

  avalanche photodiode = −58 dBm

  PIN photodiode = −42 dBm

- Optical Signal Range (OSR)

  (Sometimes called dynamic range)

  OSR $\leqslant$ 30 dB

13. A 1:1 bifurcation device is required for coupling between a single fiber cable and a fiber optic transmitter/receiver. This device has the following state-of-the-art parameters.

	Main branch to stubs	Stubs to main branch
power division	3 dB	–
excess loss	1 dB	1 dB
2 connector losses @ 1 dB each	2 dB	2 dB
Total loss =	6 dB	3 dB

14. Dual data bus controllers are required due to the echeloning requirements and for graceful degradation and system reliability.

B. CANDIDATE CONFIGURATION I, MULTIDROP T

1. Characteristics

Due to the large number of connector, coupler and miscellaneous losses, this configuration requires use of injection laser diode sources, APD diode detectors, and single fiber cable to be feasible.

A design using a one-to-one power division T-coupler requires an electrical repeater after every four users. In order to improve on that design, a 9:1 power division T-coupler might be used. This, however, fails to substantially increase the repeater spacing. The multidrop T-coupler configuration is shown in Figure 5.

The optical power losses for each branch of the 1:1 T-coupler are listed below.

	Stub branch	Main branch
optical power division	3 dB	3 dB
excess loss	1 dB	1 dB
2 connector losses @ 1 dB each	2 dB	2 dB
Total loss @	6 dB	6 dB

Assuming an electrical repeater following every four users, the transmitter-to-receiver optical power loss would be:

	Longest T/R path	Shortest T/R path
o T-couplers	(4) 24 dB	(1) 6 dB
o bifurcation device	(2) 9 dB	(2) 9 dB
o RCVR/XMTR connectors	(2) 2 dB	(2) 2 dB
o cable attenuation, 200 m @ 20 dB/km = 4 dB	(4) 16 dB	(1) 0 dB
o device-to-device mfg., thermal, and aging variations	10 dB	0 dB
Total path loss =	61 dB	17 dB

The optical signal range to be accepted by the optical receiver is 61 dB - 17 dB = 44 dB.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity required of this fiber optic receiver is +5 dBm -(61 dB) = -56 dBm.

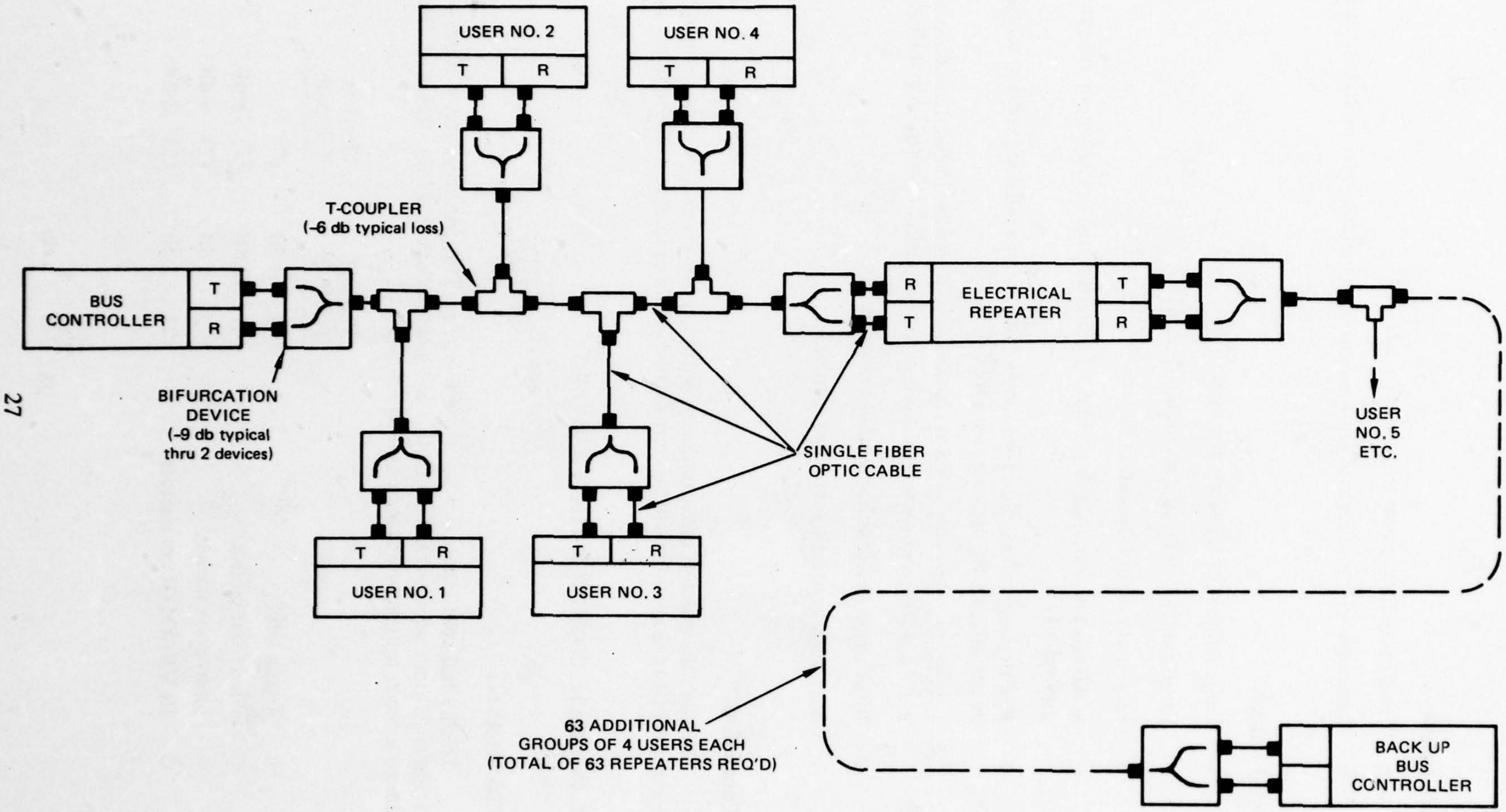


Figure 5. Candidate configuration 1, multidrop T.

2. Advantages

- o Fiber optic throughout from user to user
- o Relatively easy one-for-one replacement with metallic wire multidrop bus system

3. Disadvantages

- o Large number of repeaters required (63)
- o Large number of T-couplers required (256)
- o Large number of bifurcation devices required (304)
- o Serial bus has many single points of failure throughout its length, resulting in poor survivability.
- o Requires use of injection laser diodes; the life of available production units is not as yet sufficiently high for this application.
- o Injection laser diodes and APD detectors required in this configuration are temperature sensitive and require additional compensation circuitry over LED/PIN designs.
- o Bifurcation device is not a proven component.
- o Very large optical signal range required

4. Conclusion

Although the disadvantages appear to outweigh the advantages, this is a unique and important configuration and it will be considered a viable candidate in the systems analysis.

C. CANDIDATE CONFIGURATION II, HYBRID

1. Characteristics

This hybrid configuration is shown in Figure 6. This configuration requires use of injection laser diode sources, APD detectors and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path		Shortest T/R path	
o T-couplers	(4)	24 dB	(0)	–
o 9-port star coupler	(4)	72 dB	(1)	18 dB
o bifurcation device	(2)	9 dB	(2)	9 dB
o RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB

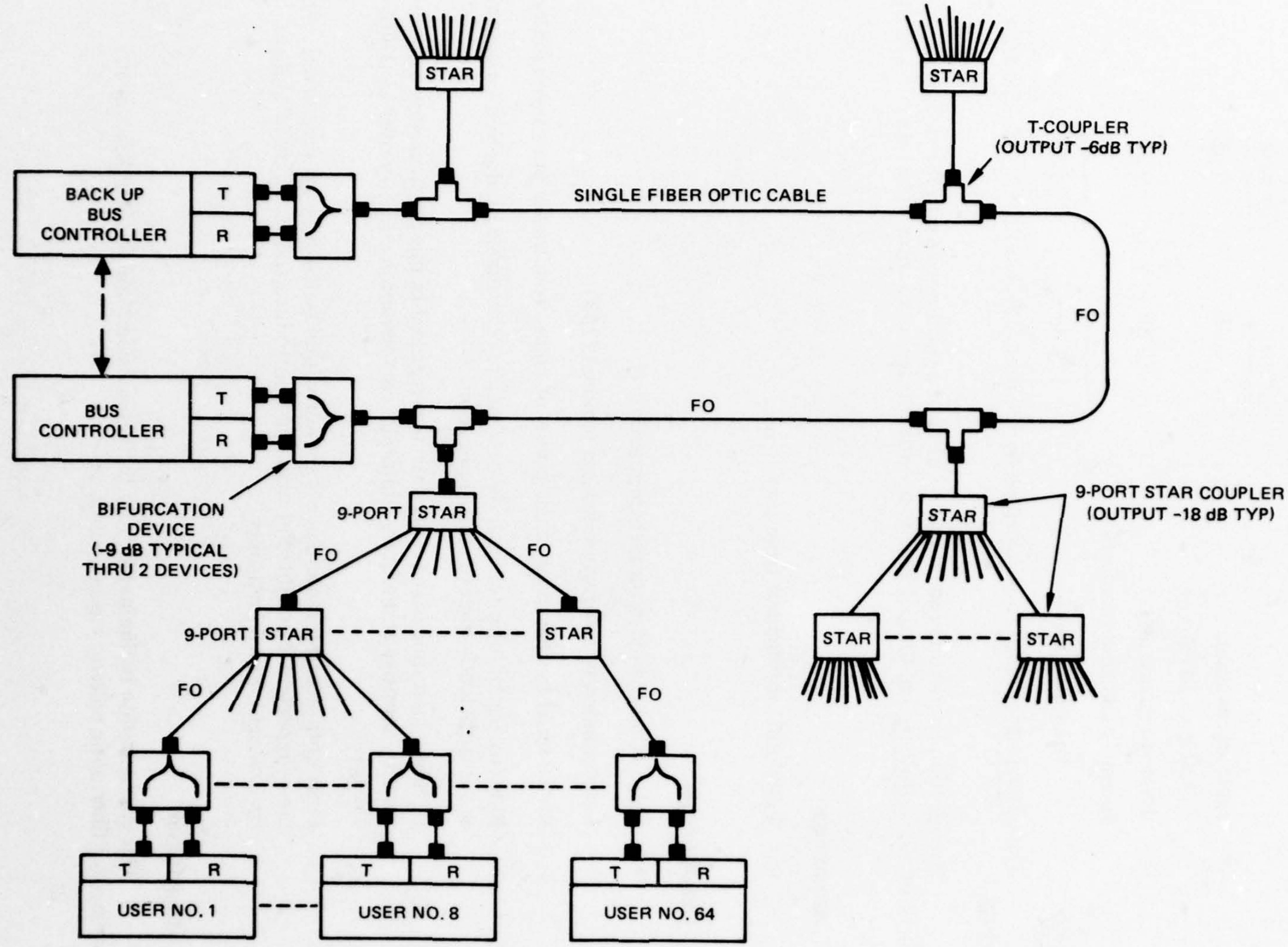


Figure 6. Candidate configuration II, hybrid.

		Longest T/R path	Shortest T/R path
o	cable attenuation, 200 m @ 20 dB/km	4 dB	0 dB
o	device-to-device mfg., thermal and aging variations	10 dB	0 dB
	Total path loss =	121 dB	29 dB

The optical signal range to be accepted by the optical receiver is 121 dB – 29 dB = 92 dB.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity required of this fiber optic receiver is +5 dBm – (121 dB) = –116 dBm.

2. Advantages

- Fiber optic throughout from user to user

3. Disadvantages

- Large number of star couplers required (36)
- Large number of bifurcation devices required (258)
- Partial serial bus has many single points of failure resulting in poor survivability.
- Requires use of injection laser diodes; the life of available production units is not as yet sufficiently high for this application.
- Injection laser diodes and APD detectors required in this configuration are temperature sensitive and require additional compensation circuitry over LED/PIN designs.
- Fiber optic receiver requirements are not within state-of-the-art parameters. The use of repeaters is possible but would also introduce additional disadvantages (size, weight, power, reliability).

4. Conclusion

This configuration is eliminated from further consideration for MIFASS due to impractical fiber optic receiver requirements.

D. CANDIDATE CONFIGURATION III, HYBRID WITH MULTIPLEXING

1. Characteristics

This configuration is shown in Figure 7. It requires use of injection laser diode sources, APD detectors and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path		Shortest T/R path	
o bifurcation devices	(2)	9 dB	(2)	9 dB
o 9-port star coupler	(2)	36 dB	(1)	18 dB
o T-coupler	(4)	24 dB		–
o RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB
o cable attenuation, 200 m @ 20 dB/km		4 dB		0 dB
o device-to-device mfg., thermal and aging variations		10 dB		0 dB
Total path loss =		85 dB		29 dB

The optical signal range to be accepted by the optical receiver is: 85 dB - 29 dB = 56 dB.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity required of this fiber optic receiver is +5 dBm - (85 dB) = -80 dBm.

2. Advantages

- Fiber optic throughout from user to user
- Only 4 star couplers and 4 T-couplers required

3. Disadvantages

- Large number of MUX/DEMUX units required (32)
- Large number of bifurcation devices required (34)
- Partial serial bus has many single points of failure resulting in poor survivability.
- Requires use of injection laser diodes; the life of available production units is not as yet sufficiently high for this application.

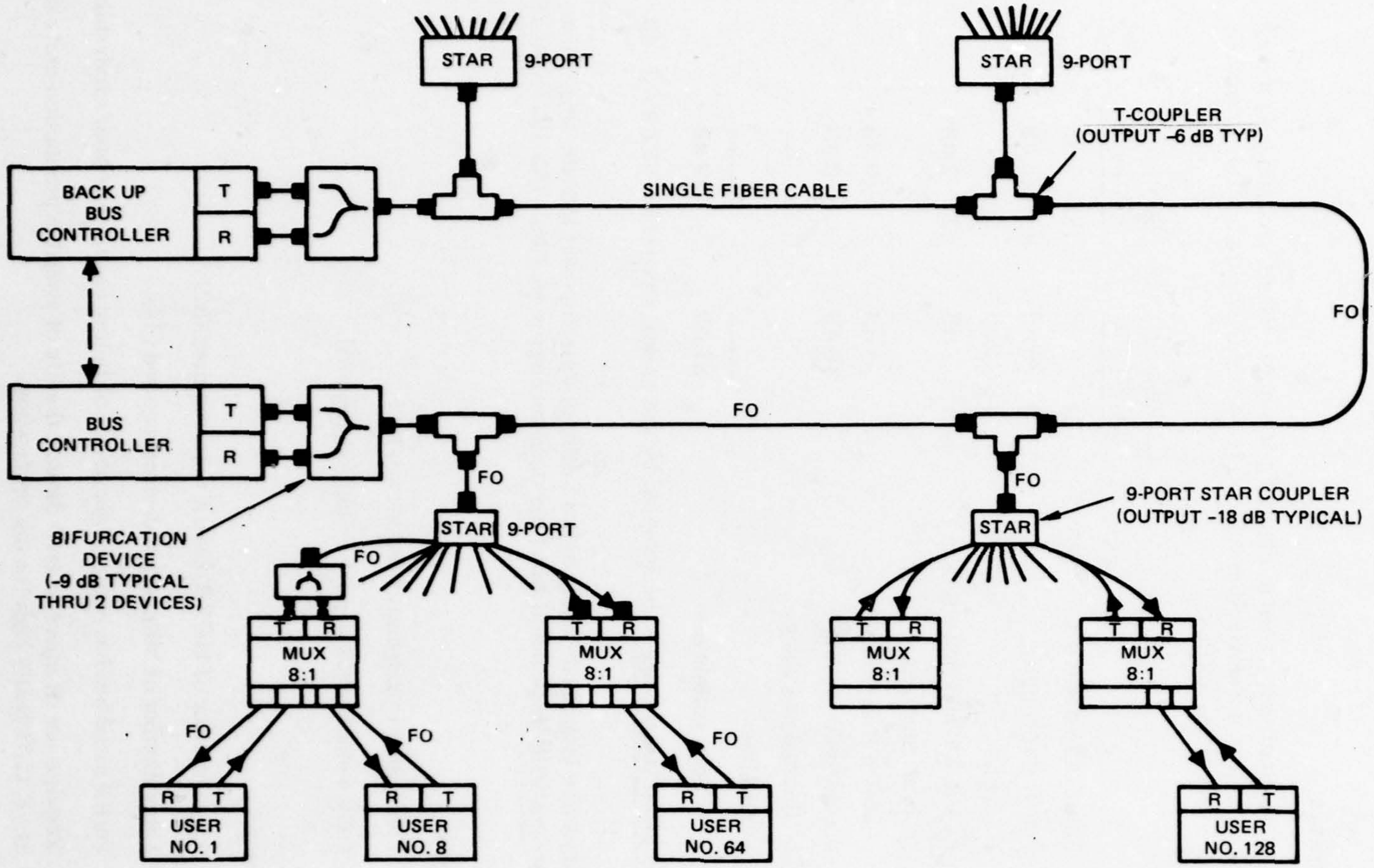


Figure 7. Candidate configuration III, hybrid with multiplexing.

- Injection laser diodes and APD detectors required in this configuration are temperature sensitive and require additional compensation circuitry over LED/PIN designs.
- The addition of repeaters in appropriate places may improve this configuration's performance but would also introduce additional disadvantages such as size, weight, power, reliability.
- Large number of additional point-to-point fiber optic links (256) were introduced between user and MUX/DEMUX units.
- The fiber optic receiver requirements are not within state-of-the-art parameters.

4. Conclusion

This configuration introduces a single stage of multiplexing in order to reduce maximum optical loss. The results still exceed state-of-the-art and this configuration is not considered practical for further study. It is therefore eliminated from consideration as a candidate in the systems analysis.

E. CANDIDATE CONFIGURATION IV, REFLECTIVE STAR COUPLER TREE

1. Characteristics

This configuration is shown in Figure 8. It requires use of injection laser diode sources, APD detectors and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path		Shortest T/R path	
o bifurcation devices	(2)	9 dB	(2)	9 dB
o 9-port star coupler	(4)	72 dB	(1)	18 dB
o 6-port star coupler	(1)	16 dB		–
o RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB
o cable attenuation, 200 m @ 20 dB/km		4 dB		0 dB
o device-to-device mfg, thermal and aging variations		10 dB		0 dB
Total path loss =		113 dB		29 dB

The <u>optical signal range</u> to be accepted by the optical receiver is 113 dB - 29 dB = 84 dB.

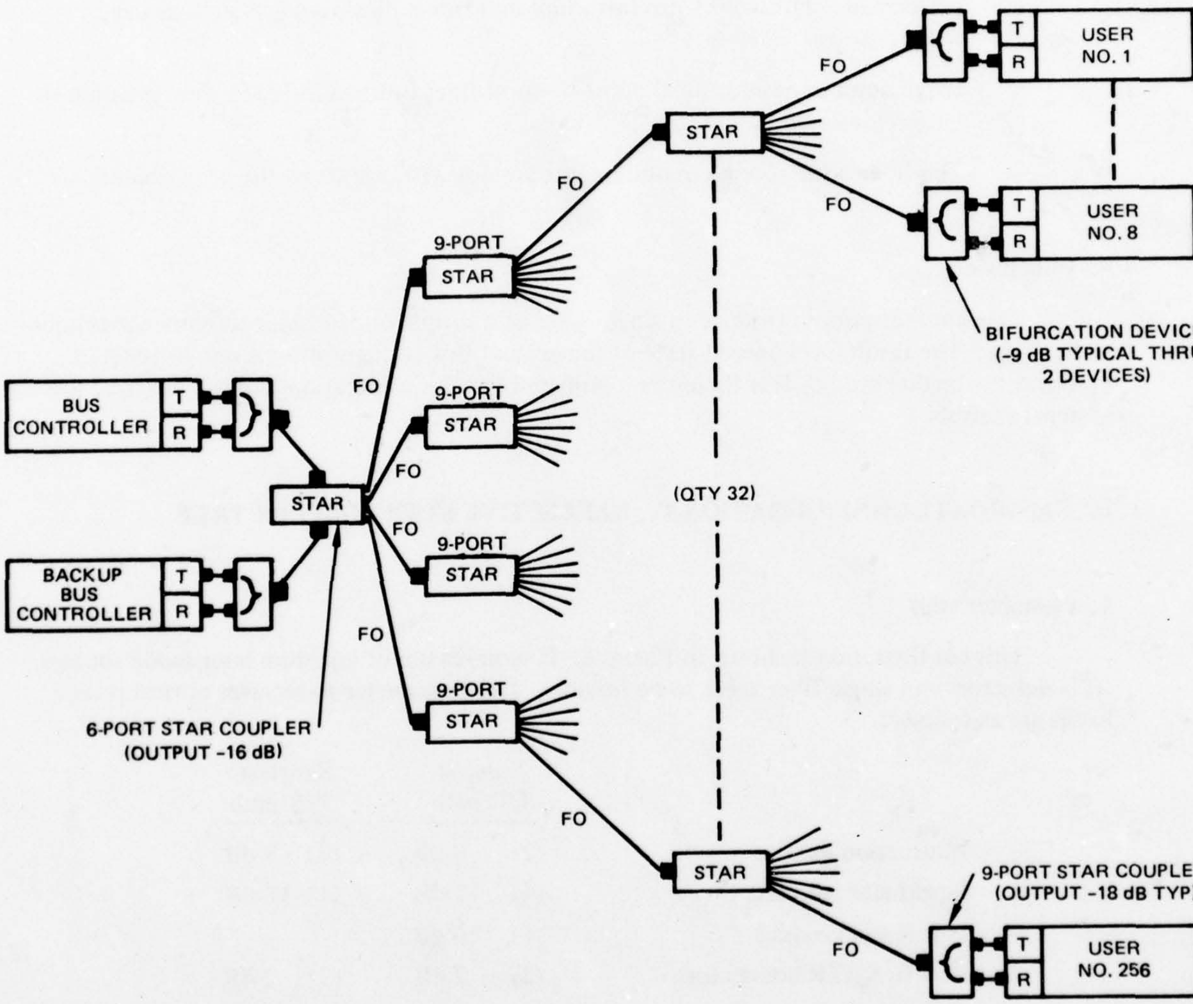


Figure 8. Candidate configuration IV, reflective star coupler tree.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity required of this fiber optic receiver is +5 dBm – (113 dB) = –108 dBm.

2. Advantages

- Fiber optic cable user to user
- No T-couplers required
- No multiplexers/demultiplexers required

3. Disadvantages

- Large number of star couplers required (37)
- Large number of bifurcation devices required (257)
- The six-port star coupler is a critical node whose failure would destroy entire bus operation.
- Requires use of injection laser diodes; the life of available production units is not as yet sufficiently high for this application.
- Injection laser diodes and APD detectors required in this configuration are temperature-sensitive and require additional compensation circuitry over LED/PIN designs.
- The addition of electrical repeaters is required to make this configuration practical. These repeaters would also introduce additional disadvantages such as size, weight, power, and reliability.
- The fiber optic receiver requirements are not within state-of-the-art parameters.

4. Conclusion

This configuration is eliminated from further consideration for MIFASS due to impractical fiber optic receiver requirements.

F. CANDIDATE CONFIGURATION V, REFLECTIVE STAR COUPLER TREE WITH MULTIPLEXING

1. Characteristics

This configuration is shown in Figure 9. It requires use of injection laser diodes sources, APD detectors and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

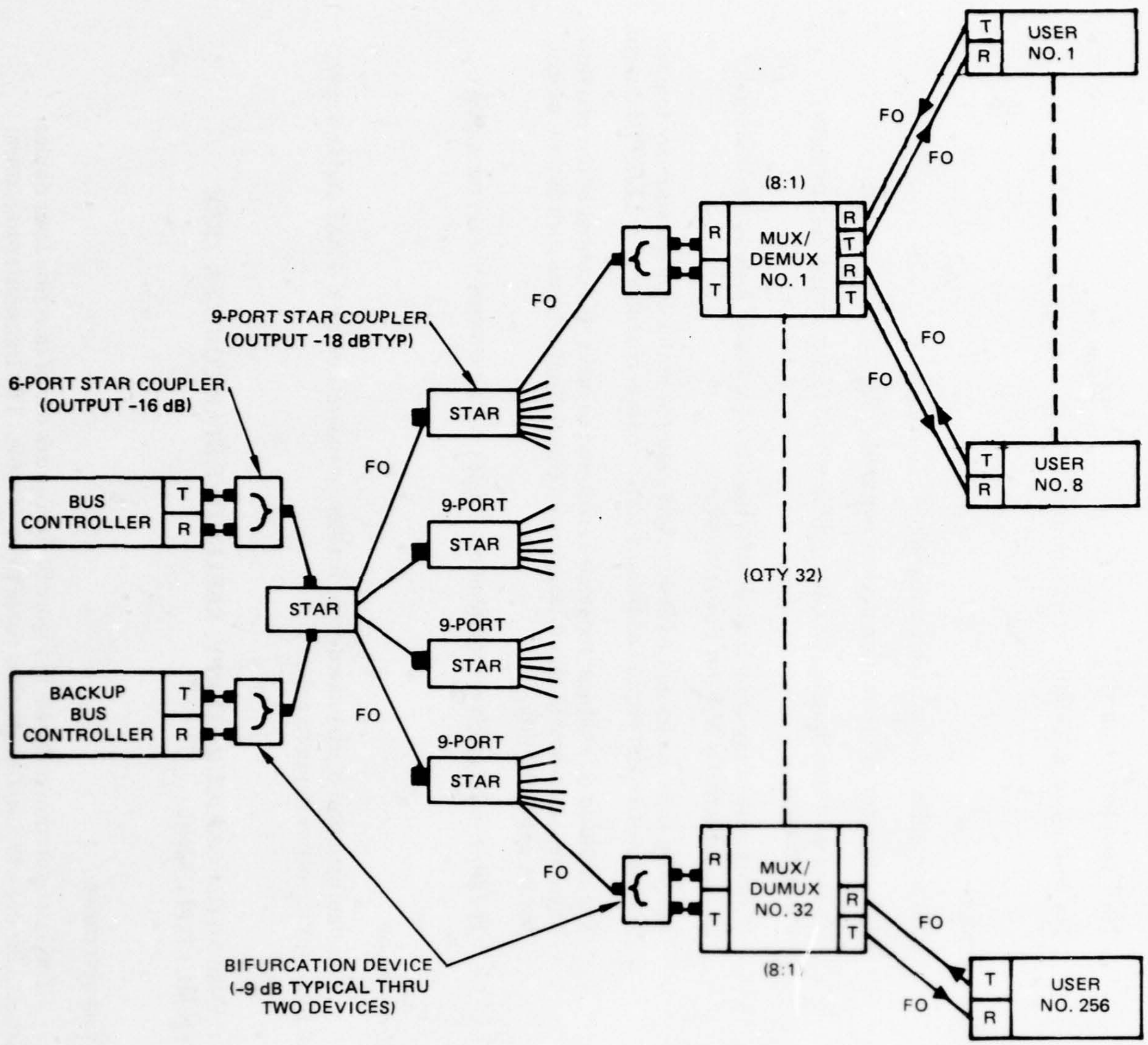


Figure 9. Candidate configuration V, reflective star coupler tree with multiplexing.

		Longest T/R path		Shortest T/R path
o bifurcation devices	(2)	9 dB	(2)	9 dB
o 9-port star coupler	(2)	36 dB	(1)	18 dB
o 6-port star coupler	(1)	16 dB		–
o RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB
o cable attenuation, 200m @ 20 dB/km		4 dB		0 dB
o device-to-device mfg., thermal and aging variations		10 dB		0 dB
Total path loss =		77 dB		29 dB

The optical signal range to be accepted by the optical receiver is 77 dB - 29 dB = 48 dB.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity required of the fiber optic receiver is +5 dBm -(77 dB) = -72 dBm.

2. Advantages

- Only 5 star couplers required, no T-couplers
- Fiber optic cable user to user

3. Disadvantages

- Large number of MUX/DEMUX units required (32)
- Large number of bifurcation devices required (33)
- Large number of additional point-to-point fiber optic links were introduced between user and MUX/DEMUX units
- Requires use of injection laser diodes; the life of available production units is not as yet sufficiently high for this application.
- Injection laser diodes and APD detectors required in this configuration are temperature sensitive and require additional compensation circuitry over LED/PIN designs.
- The six-port star coupler is a node whose failure would shut down entire bus operation.
- The fiber optic receiver requirements are not within state-of-the-art parameters.

4. Conclusion

This configuration introduced a single state of multiplexing in order to reduce maximum optical loss. The results are marginal at best and this configuration is not considered practical for further study. It is therefore eliminated from consideration as a candidate in the systems analysis.

G. CANDIDATE CONFIGURATION VI, TRANSMISSIVE STAR COUPLER WITH TWO STAGE MULTIPLEXING

1. Characteristics

This configuration is shown in Figure 10. It may be implemented with LED sources, PIN diode detectors, and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path	Shortest T/R path
o 10-port star coupler	(1) 19 dB	(1) 19 dB
o RCVR/XMTR connectors	(2) 2 dB	(2) 2 dB
o cable attenuation (very short cable)	—	—
o device-to-device mfg, thermal and aging variations	10 dB	0 dB
Total path loss =	31 dB	21 dB

The optical signal range to be accepted by the optical receiver is 31 dB - 21 dB = 10 dB.

A LED can couple −10 dBm of optical power into the single fiber, therefore the sensitivity required of the fiber optic receiver is −10 dBm −(31 dB) = −41 dBm.

In addition to the fiber optic bus, there are many short point-to-point fiber optic links in this configuration between MUXes and USERS. These links can be implemented with LED sources, PIN detectors and single fiber cable.

2. Advantages

- Only 1 star coupler required, no T-couplers
- Fiber optic cable user to user
- No bifurcation devices required

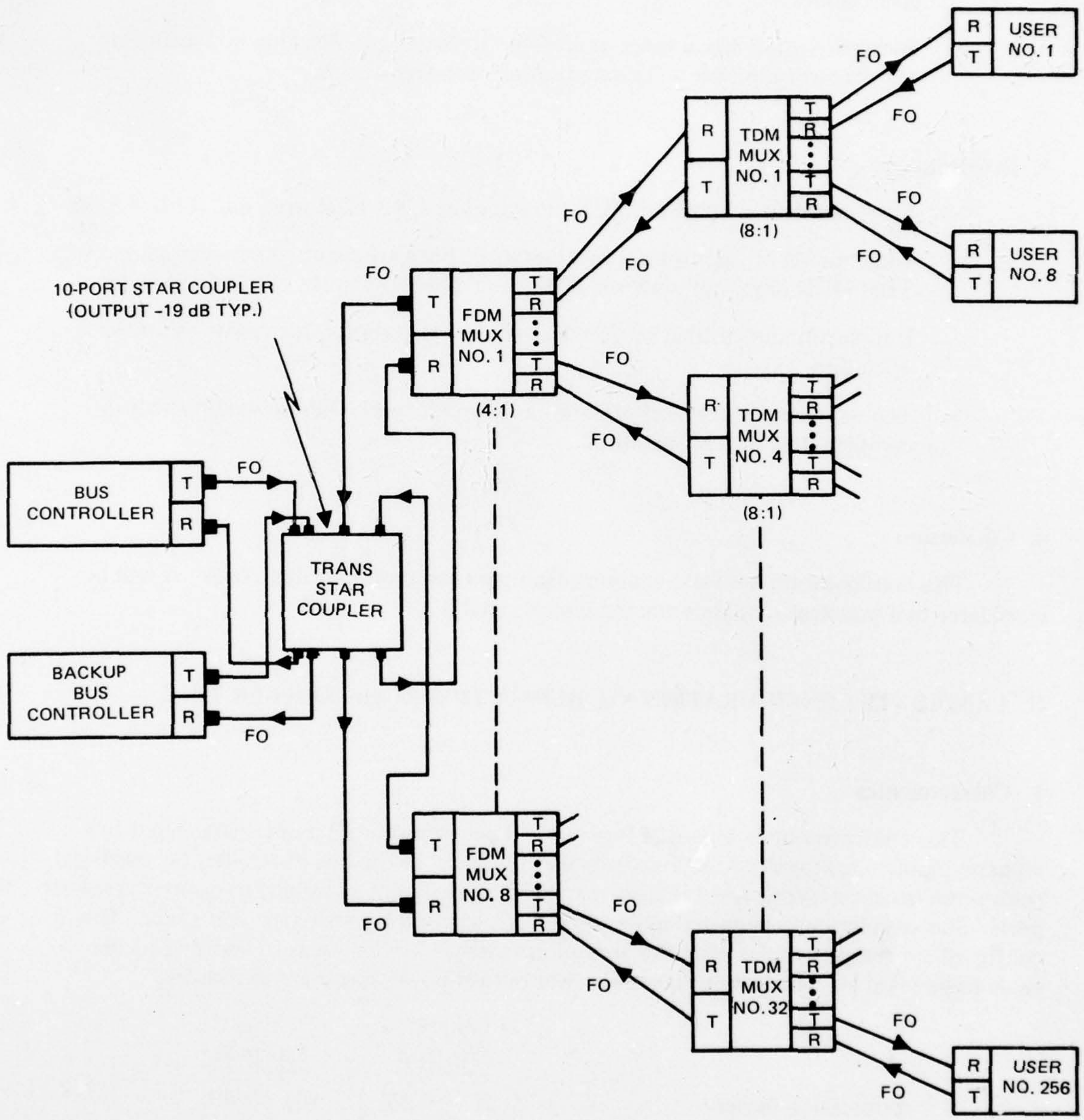


Figure 10. Transmissive star coupler with two stage multiplexing.

- This configuration uses LED diode drivers, PIN diode detectors and single fiber cable rather than the more sophisticated and costly injection laser diodes and APD diodes.
- Receiver optical signal range and sensitivity requirements allow for sufficient system optical power margin and simpler receiver design.

3. Disadvantages

- Large number of MUX/DEMUX units required, 32 TDM units and 8 FDM units
- Large number of point-to-point fiber optic links are required between users and TDM MUX units and between TDM and FDM MUX units, total of 586 links.
- Double amount of fiber optic cable required due to simplex versus half duplex operation.
- The star coupler in this configuration is a node whose failure would result in complete loss of bus operation.

4. Conclusion

This configuration has some unique advantages and merits further study. It will be considered as a practical candidate for the systems analysis.

H. CANDIDATE CONFIGURATION VII, REFLECTIVE STAR COUPLER TREE

1. Characteristics

This configuration is shown in Figure 11. Each group of 32 users is connected to a separate input/output port of the bus controller. Internal to the bus controller, the electrical transmitter/receiver is connected to eight parallel fiber optic input/output transmitter/receiver ports. Star couplers are connected as required in groups of 32 users to the controller. This configuration requires use of injection laser diode sources, APD detectors, and single fiber cable to be feasible. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path		Shortest T/R path	
o bifurcation devices	(2)	9 dB	(2)	9 dB
o 9-port star coupler	(2)	36 dB	(1)	18 dB
o 5-port star coupler	(1)	16 dB		–
o RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB
o cable attenuation 200m @ 20 dB/km		4 dB		0 dB

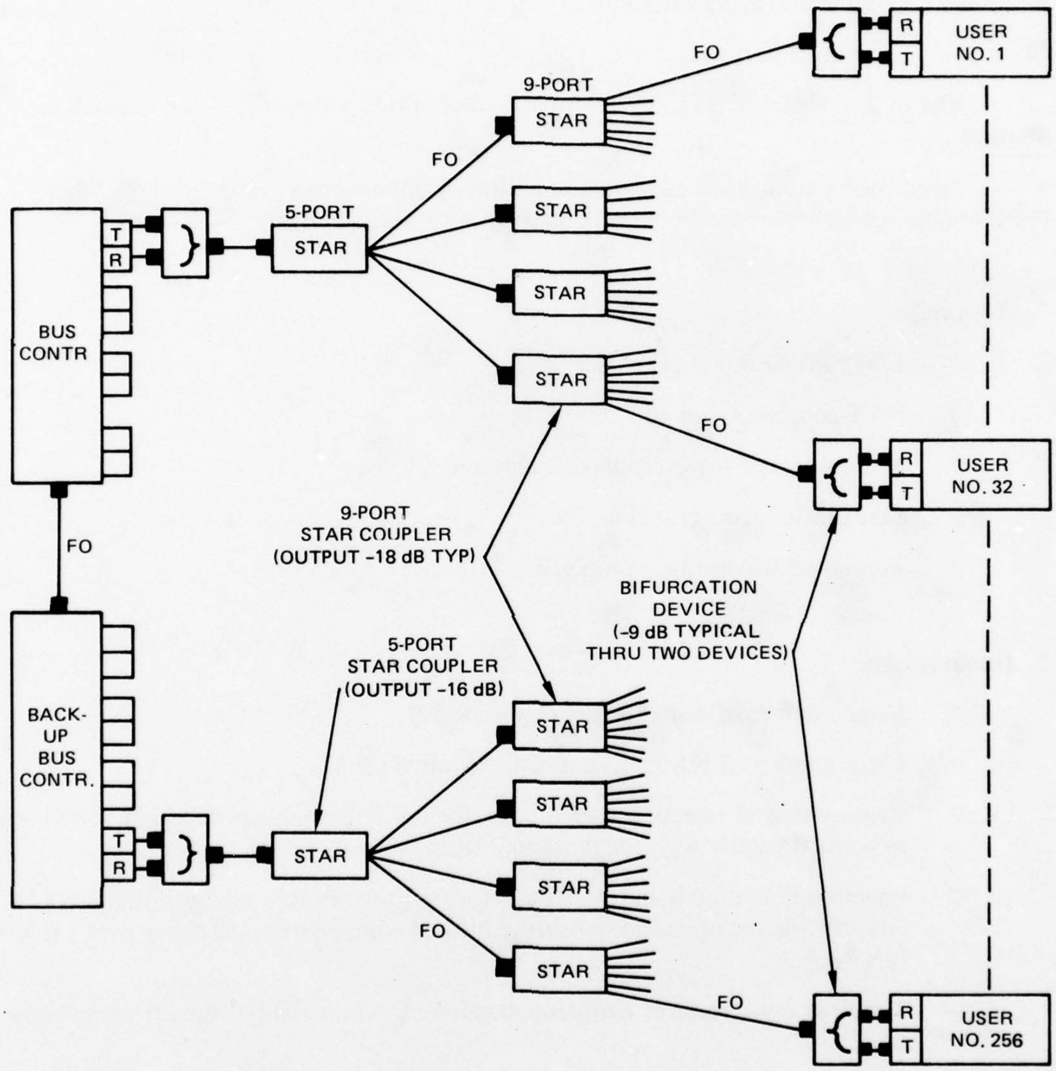


Figure 11. Reflective star coupler tree configuration.

		Longest T/R path	Shortest T/R path
o	device to device mfg, thermal and aging variations	10 dB	0 dB
	Total path loss	77 dB	29 dB

The optical signal range to be accepted by the optical receiver is 77 dB - 29 dB = 48 dB.

An injection laser diode can couple +5 dBm of optical power into the single fiber, therefore the sensitivity of the fiber optic receiver is +5 dBm -(77 dB) = -72 dBm.

2. Advantages

- Fiber optic cable user to user
- No T-couplers required
- No multiplexers/demultiplexers required
- Ease of modular expansion
- Very good survivability properties

3. Disadvantages

- Large number of star couplers required (40)
- Large number of bifurcation devices required (264)
- Requires use of injection laser diodes, the life of available production units is not as yet sufficiently high for this application.
- Injection laser diodes and ADP detectors required in this configuration are temperature sensitive and require additional compensation circuitry over LED/PIN designs.
- The fiber optic receiver requirements are not within state-of-the-art parameters.

4. Conclusion

The maximum optical losses in this configuration are marginal, therefore it will be eliminated from further consideration as a candidate for the systems analysis. It contains some unique advantages which will be incorporated into configuration number VIII.

I. CANDIDATE CONFIGURATION VIII, SINGLE REFLECTIVE STAR COUPLER

1. Characteristics

This configuration is shown in Figure 12. It consolidates the 5-star couplers of configuration VII into one 33-port coupler. The associated optical power savings should bring the configuration from marginal to within specification. This configuration can be implemented with LED sources, APD detectors, and single fiber cable. The transmitter-to-receiver optical power losses are as follows:

		Longest T/R path		Shortest T/R path	
o	bifurcation devices	(2)	9 dB	(2)	9 dB
o	33-port star coupler	(1)	24 dB	(1)	24 dB
o	RCVR/XMTR connectors	(2)	2 dB	(2)	2 dB
o	cable attenuation 200m @ 20 dB/km		4 dB		0 dB
o	device-to-device mfg., thermal and aging variations		10 dB		0 dB
	Total path loss =		49 dB		35 dB

The optical signal range to be accepted by the optical receiver is 49 dB – 35 dB = 14 dB.

A LED can couple –10 dBm of optical power into the single fiber, therefore the sensitivity required of the fiber optic receiver is –10 dBm – (49 dB) = –59 dBm.

In this configuration, the use of a LED/APD or LASER/PIN diode combination requires about the same receiver sensitivity and optical signal range. The preferred choice is the LED/APD combination because of size, weight, power dissipation, cost, and reliability considerations.

2. Advantages

- o Fiber optic cable user to user
- o No T-couplers required
- o No multiplexers/demultiplexers required
- o Ease of modular expansion
- o Very good survivability properties
- o Only eight 33-port star couplers required maximum
- o Receiver optical signal range requirement and minimum sensitivity requirement allow for adequate system optical power margin and simpler receiver design.

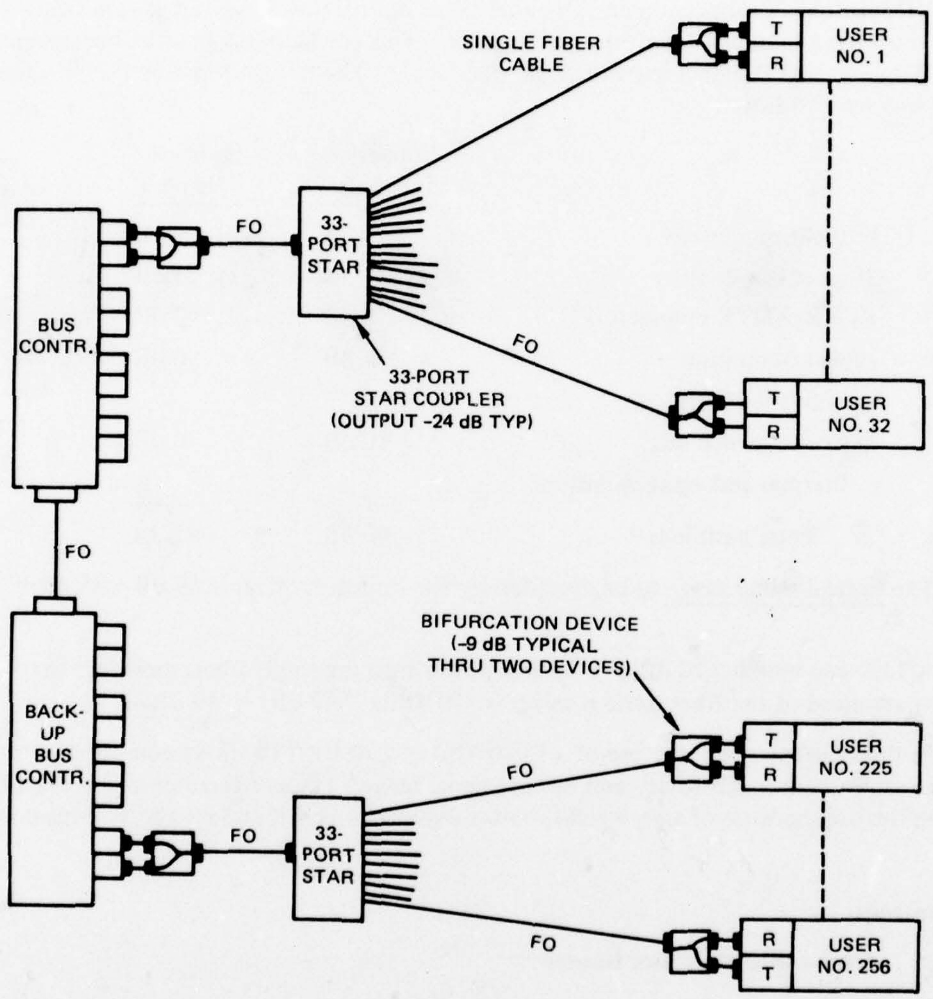


Figure 12. Single reflective star coupler.

3. **Disadvantages**

- Large number of bifurcation devices required (264)
- No 33-port star couplers have been built to date. A number of manufacturers are presently building R&D units.
- Bifurcation device is not a proven component.

4. **Conclusion**

This configuration has many advantages including an adequate optical power margin and will be considered as a candidate in the systems analysis.

J. CANDIDATE CONFIGURATION IX, SINGLE TRANSMISSIVE STAR COUPLER

1. **Characteristics**

This configuration is shown in Figure 13. It is identical to configuration VIII with the exception that the transmissive star coupler has replaced the reflective star coupler. This substitution eliminates the need for bifurcation devices and thereby saves 9 dB of optical power through each transmitter-to-receiver path. This configuration permits use of a LED diode source and APD diode detector. Single fiber cable is used. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path	Shortest T/R path
o 33-port star coupler	(1) 24 dB	(1) 24 dB
o RCVR/XMTR connectors	(2) 2 dB	(2) 2 dB
o cable attenuation 400 m @ 20 dB/km	8 dB	0 dB
o device-to-device mfg., thermal and aging variations	10 dB	0 dB
Total path loss =	44 dB	26 dB

The optical signal range to be accepted by the optical receiver is 44 dB - 26 dB = 18 dB.

An LED can couple -10 dBm of optical power into the single fiber, therefore the sensitivity required of the fiber optic receiver is -10 dBm -(44 dB) = -54 dBm.

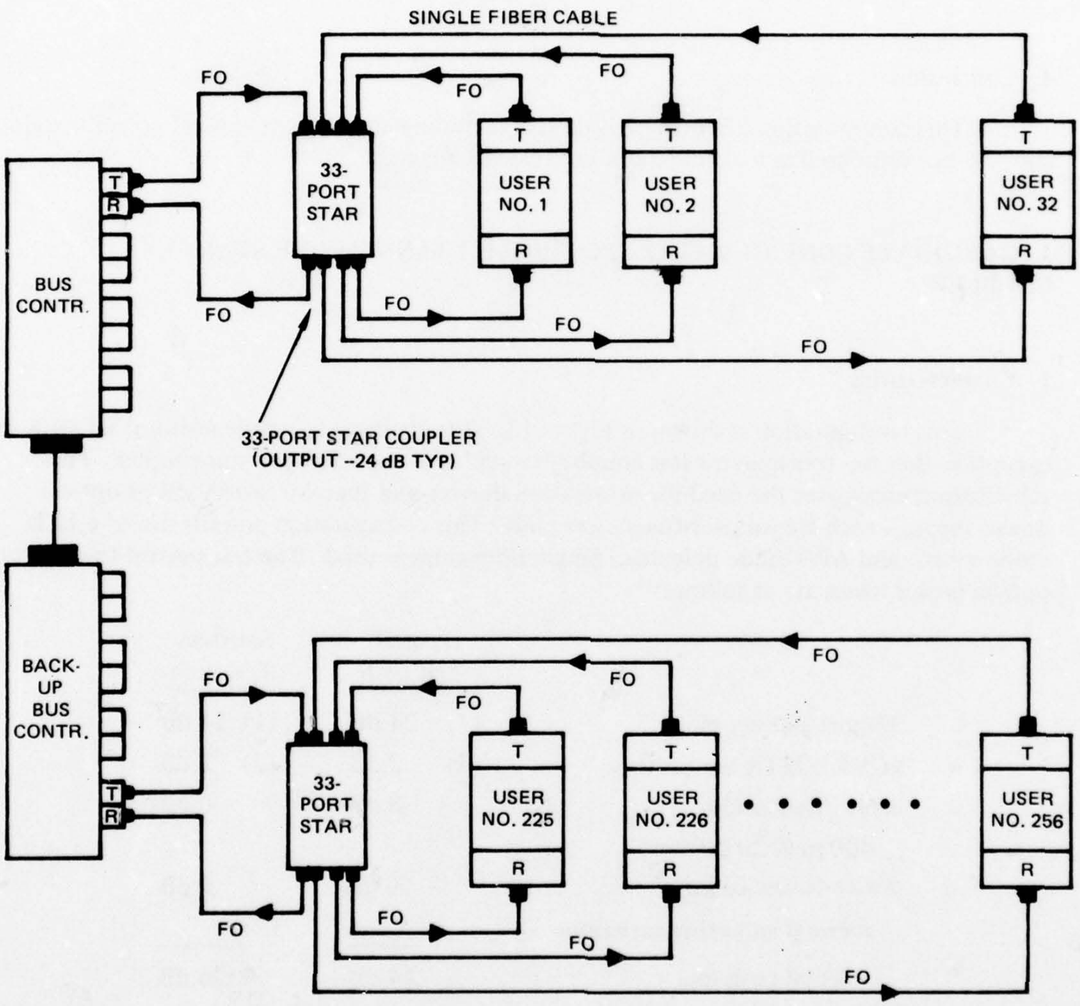


Figure 13. Single transmissive star coupler.

2. Advantages

- Fiber optic cable user to user
- No T-couplers, no MUX/DEMUX units, no bifurcation devices nor repeaters required
- Only eight 33-port star couplers required maximum
- Ease of modular expansion
- Very good survivability properties
- Design can be implemented with LED diode sources
- The system has a good optical power margin which will simplify the optical receiver design and contribute to a low bit error rate.

3. Disadvantages

- The amount of fiber optic cable required for this configuration is doubled due to simplex versus half duplex operation.
- No 33-port star couplers have been built to date. A number of manufacturers are presently building R&D units.

4. Conclusion

This configuration has definite net advantages and will be considered as a candidate in the systems analysis.

K. CANDIDATE CONFIGURATION X, MULTIDROP STAR WITH REPEATERS

1. Characteristics

This configuration is shown in Figure 14. It is essentially a unidirectional ring configuration with transmissive star couplers in place of the normal T-couplers. An electrical repeater is inserted between each coupler with a gain equivalent to the loss in one coupler. This configuration permits use of an LED diode source, APD diode detector, and single fiber cable. The transmitter-to-receiver optical power losses are as follows:

	Longest T/R path	Shortest T/R path
o 33-port star coupler	(1) 24 dB	(1) 24 dB
o RCVR/XMTR connectors	(2) 2 dB	(2) 2 dB
o cable attenuation 400 m @ 20 dB/km	8 dB	0 dB

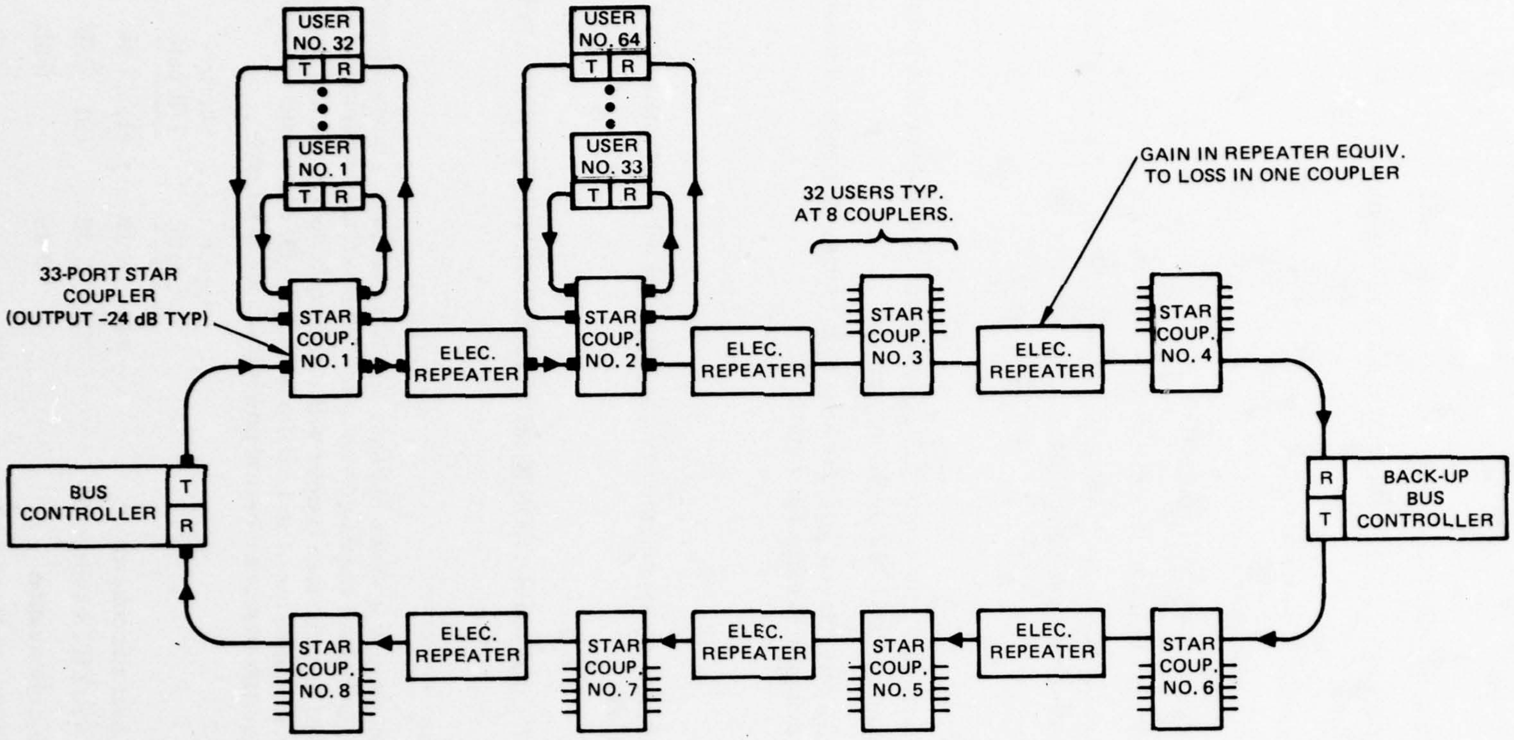


Figure 14. Multidrop star configuration with repeaters.

	Longest T/R path	Shortest T/R path
o device-to-device mfg., thermal and aging variations	10 dB	0 dB
Total path loss =	44 dB	26 dB

The optical signal range to be accepted by the optical receiver is 44 dB - 26 dB = 18 dB.

An LED can couple −10 dBm of optical power into the single fiber, therefore the sensitivity required of the fiber optic receiver is −10 dBm −(44 dB) = −54 dBm.

2. Advantages

- Fiber optic cable user to user
- No T-couplers, no MUX/DEMUX units, nor bifurcation devices required
- Only eight 33-port star couplers required maximum
- Ease of modular expansion
- Design can be implemented with LED diode driver, single fiber cable and an APD diode detector which will simplify transmitter design.

3. Disadvantages

- Due to simplex operation, the amount of fiber optic cable required for this configuration from coupler to user is doubled.
- Survivability is poor due to serial nature of bus. Failure of any coupler or repeater results in complete failure of bus operation.
- Total of six repeaters required.
- No 33-port couplers have been built to date. However this design will work equally well with 16-port couplers.

4. Conclusion

This configuration is similar to configuration IX in the coupler/user area, but has the disadvantages of a partial serial configuration with repeaters. Its performance, therefore, will not be as good as configuration IX and it will be eliminated from further consideration as a systems analysis candidate.

VIII. EVALUATION OF REMAINING CANDIDATE SYSTEMS

A. PERFORMANCE ANALYSIS

The methodology for the performance analysis which follows has been described in Section VI. Table 3 lists each of the remaining candidate systems with the determination of how each meets the listed performance evaluation criteria. The ratings are subjective except for actual weight, volume, and optical power losses, which were estimated for each system. The allowable ratings were either excellent, very good, good, fair, or poor.

Table 3. Performance evaluation of remaining candidate systems.

EVALUATION CRITERIA	CANDIDATE SYSTEM I	CANDIDATE SYSTEM VI	CANDIDATE SYSTEM VIII	CANDIDATE SYSTEM IX
Weight	Poor	Very good	Very good	Excl
Volume	Poor	Fair	Very good	Excl
Reliability, maintainability, availability	Fair	Good	Excl	Excl
Survivability	Fair	Good	Excl	Excl
Graceful degradation	Poor	Good	Excl	Excl
Flexibility	Good	Excl	Excl	Excl
Transmitter-to-receiver optical losses	Fair	Excl	Very good	Excl
Primary power	Good	Fair	Excl	Excl
Overall rating =	Fair	Good	Very good	Excl

Candidate system IX is the clear choice in every area of performance. Candidate VIII also scores very well, but the bifurcation device it utilizes penalizes the system in the areas of weight and volume. The other two candidates, while possibly able to meet the stated requirements, rank far behind candidates VIII and IX.

B. RATIONALE FOR PERFORMANCE RATINGS

1. Weight and Volume

Table 4 lists the weight estimates and Table 5 lists the volume estimates for the major components of each of the four candidate fiber optic data bus systems. Candidate system IX is clearly the lightest in weight and the smallest in volume due largely to the simplicity of the design. This system requires no bifurcation devices, multiplexers, or electrical repeaters.

2. Reliability, Maintainability, Availability

Candidate system I was rated only FAIR in this evaluation criteria because of the serial nature of the data bus, the number of active electrical repeaters required in the serial chain and the large number of T-couplers required from end to end. A failure in any of these components or in the main trunk of the bus causes a catastrophic failure in the entire bus system. In addition, the injection laser diode used in 258 fiber optic transmitter modules in this design presently has a shorter operating life than the light emitting diodes used in the other candidate system designs. Candidate system VI was rated only GOOD because its passive star coupler is a node whose loss would cause failure of the entire bus. In addition, failure of any of the multiplexers will cause loss of a large number of bus users. Candidate systems VIII and IX were rated EXCELLENT because each has only one passive star coupler between any transmitter and receiver.

3. Survivability and Graceful Degradation

Both candidate systems VIII and IX were rated EXCELLENT in survivability and graceful degradation because their architectures are such that they have no single active point of catastrophic failure and each could be easily programmed for graceful degradation. Further, their architecture facilitates implementation of a redundant fiber optic data bus or a distributed bus control scheme.

4. Flexibility

Candidate Systems VIII and IX were rated EXCELLENT in flexibility because these data bus systems can be built in a modularly expandable fashion to accommodate the smallest to the largest shelter in increments of 8, 16, or 32 users.

Table 4. Weight estimates of candidate systems.

COMPONENT	UNIT WEIGHT, Kg.	CANDIDATE SYSTEM I		CANDIDATE SYSTEM VI		CANDIDATE SYSTEM VIII		CANDIDATE SYSTEM IX	
		QTY.	WT.	QTY.	WT.	QTY.	WT.	QTY.	WT.
• STAR COUPLERS									
5-PORT	.160	–		–		–		–	
9 & 10-PORT	.260	–		1	.26	–		–	
33-PORT	1.000	–		–		8	8.00	8	8.00
• T-COUPLER	.160	256	40.96	–		–		–	
• TDM MUX/DEMUX	.450	–		32	14.40	–		–	
• FDM MUX/DEMUX	.225	–		8	1.80	–		–	
• BIFURCATION DEVICE	.160	386	61.76	–		264	42.24	–	
• T/R MODULE (INJECTION LASER)	.210	258	54.18	–		–		–	
• T/R MODULE (LED)	.022	–		586	12.89	264	5.81	264	5.81
• REPEATER (2 T/R MODULES, LASER + 2 RETIMING CKTS)	.420	63	26.46	–		–			
• FIBER CABLE (SINGLE FIBER HEAVY DUTY CABLE)	6 Kg/Km	5.1 Km (DUPLEX)	30.60	10.2 Km (SIMPLEX)	61.20	5.1 Km (DUPLEX)	30.60	10.2 Km (SIMPLEX)	61.20
		214.0 Kg OR 471 LBS.		90.5 Kg OR 200 LBS.		86.7 Kg OR 191 LBS.		74.8 Kg OR 165 LBS.	
		POOR		VERY GOOD		VERY GOOD		EXCL	

Table 5. Volume estimates of candidate systems.

COMPONENT	UNIT VOLUME, CU. IN.	CANDIDATE SYSTEM I		CANDIDATE SYSTEM VI		CANDIDATE SYSTEM VIII		CANDIDATE SYSTEM IX	
		QTY.	VOL	QTY.	VOL	QTY.	VOL	QTY.	VOL
• STAR COUPLERS									
5-PORT	5	–		–		–		–	
9 & 10-PORT	10	–		1	10	–		–	
33-PORT	40	–		–		8	320	8	320
• T-COUPLER	5	256	1280	–		–		–	
• TDM MUX/DEMUX	64	–		32	2048	–		–	
• FDM MUX/DEMUX	32	–		8	256	–		–	
• BIFURCATION DEVICE	5	386	1930	–		264	1320	–	
• T/R MODULE (INJECTION LASER)	10	258	2580	–		–		–	
• T/R MODULE (LED)	2	–		586	1172	264	528	264	528
• REPEATER (2 T/R MODULES, LASER + 2 RETIMING CKTS)	20	63	1260	–		–		–	
• FIBER CABLE (SINGLE FIBER HEAVY DUTY CABLE)	7.8 CU.IN./ 1000 FT.	16.7K FT (DUPLEX)	130	33.4K FT (SIMPLEX)	260	16.7K FT (DUPLEX)	130	33.4K FT. (SIMPLEX)	260
		7180 CU IN OR 4.1 CU FT		3746 CU IN OR 2.1 CU FT		2298 CU IN OR 1.3 CU FT		1108 CU IN OR .64 CU FT	
		POOR		FAIR		VERY GOOD		EXCL	

5. Transmitter-to-Receiver Optical Losses

Table 6 lists the minimum optical signal required and the optical signal range required at the fiber optic receiver for each of the four candidate data bus systems. Candidate system VIII has no optical power margin and candidate system I requires an optical signal range beyond present state-of-the-art fiber optic receiver capabilities. Candidate systems VI and IX were rated excellent because they had an optical power margin after a worst case transmitter-to-receiver path loss analysis.

6. Primary Power

Candidate system VI requires over twice the number of transmit/receive modules of any other configuration. In addition, it also requires 40 multiplexing/demultiplexing units. It was, therefore, rated lowest in the requirement for primary power. Candidate system I was rated GOOD because of the 63 electrical repeaters required for that system configuration. Candidate systems VIII and IX each require only a minimum number of fiber optic transmit/receive modules and neither requires any electrical repeaters. They were therefore rated EXCELLENT in the primary power requirement category.

C. PERFORMANCE/COST ANALYSIS

The differential cost estimates of the major components of the fiber optic bus systems are given in Table 7. These acquisition costs are based on limited quantity purchases. No attempt was made at this time to include all the various additional costs associated with a life cycle system cost analysis. Any item not delineated in this list (for example, the bus controller) is assumed to be identical for each system.

The driving component in Table 7 appears to be the transmit/receive modules. The injection laser source module is estimated to cost double that of the LED source module. Candidate system I requires use of an injection laser source. Although candidate system VI makes use of LED sources, its architecture required double the number of transmit/receive modules. Candidate systems VIII and IX employ LED sources and require only a minimum number of modules. They are, therefore, clear leaders in the acquisition cost area of the system components.

The performance and cost of the four candidate systems are summarized in Table 8. Candidate system IX leads by a substantial margin in both performance and cost and is, therefore, selected as the optimum system bus candidate.

Table 6. Transmitter-to-receiver optical parameters.

	CANDIDATE SYSTEM I	CANDIDATE SYSTEM VI	CANDIDATE SYSTEM VIII	CANDIDATE SYSTEM IX
TYPE OF COMPONENTS REQUIRED	• INJECTION LASER • APD DETECTOR • SINGLE FIBER CABLE	• LED • PIN DETECTOR • SINGLE FIBER CABLE	• LED • APD DETECTOR • SINGLE FIBER CABLE	• LED • APD DETECTOR • SINGLE FIBER CABLE
MINIMUM SIGNAL AT FIBER OPTIC RECEIVER	-56 dBm (-58 dBm allowable)	-41 dBm (-42 dBm allowable)	-59 dBm (-58 dBm allowable)	-54 dBm (-58 dBm allowable)
RECEIVER OPTICAL SIGNAL RANGE REQ'D	$<$ 44 dB ($<$ 30 dB allowable)	$<$ 10 dB ($<$ 30 dB allowable)	$<$ 14 dB ($<$ 30 dB allowable)	$<$ 18 dB ($<$ 30 dB allowable)
RATING	FAIR	EXCL	VERY GOOD	EXCL

Table 7. Differential cost estimates of candidate systems.

COMPONENT	UNIT COST $	CANDIDATE SYSTEM I		CANDIDATE SYSTEM VI		CANDIDATE SYSTEM VIII		CANDIDATE SYSTEM IX	
		QTY.	COST $K	QTY.	COST $K	QTY.	COST $K	QTY.	COST $K
• STAR COUPLERS									
5-PORT	1100	–		–		–		–	
9 & 10-PORT	2000	–		1	2.0	–		–	
33-PORT	7500	–		–		8	60.0	8	60.0
• T-COUPLER	500	256	128.0	–		–		–	
• TDM MUX/DEMUX	400	–		32	12.8	–		–	
• FDM MUX/DEMUX	300	–		8	2.4	–		–	
• BIFURCATION DEVICE	500	386	193.0	–		264	132.0	–	
• T/R MODULE (INJECTION LASER)	2000	258	516.0	–		–		–	
• T/R MODULE (LED)	1000	–		586	586.0	264	264.0	264	264.0
• REPEATER (2 T/R MODULES, LASER + 2 RETIMING CKTS)	4500	63	283.5	–		–		–	
• FIBER CABLE (SINGLE FIBER HEAVY DUTY CABLE)	2\underline{50}$/m.	5.1 Km (DUPLEX)	12.8	10.2 Km (SIMPLEX)	25.5	5.1 Km (DUPLEX)	12.8	10.2 Km (SIMPLEX)	25.5
		$1133 K		$629 K		$469 K		$350 K	

Table 8. Performance/cost summary of candidate bus systems.

	CANDIDATE SYSTEM I	CANDIDATE SYSTEM VI	CANDIDATE SYSTEM VIII	CANDIDATE SYSTEM IX
PERFORMANCE RATING	FAIR	GOOD	VERY GOOD	EXCL
DIFFERENTIAL COST	$1007 K	$629 K	$469 K	$350 K

IX. OPTIMUM SYSTEM DEVELOPMENT

A. DESCRIPTION

The process of determining an optimum system design includes an iterative process wherein all the variables in the design are exercised and each resultant system evaluated. Available time and space in this report permitted examination of only a limited number of important variables in arriving at the single transmissive fiber optic star coupler bus system shown in Figure 13 as the optimum system. Those variables that were examined included bundle fiber technology versus single fiber technology, injection laser source modules versus LED source modules, PIN photodetector modules versus APD detector modules, T-couplers versus star couplers, transmissive star couplers versus reflective star couplers, active couplers versus passive couplers, and cascading couplers versus single couplers and multiplexing.

Although the investigation and analysis described in this report indicate positive approaches toward design of a fiber optic bus system to satisfy MIFASS requirements, a number of design problems remain. These problems require additional investigation. A short discussion of each of these problems follows.

1. As previously stated, the MIFASS equipments are housed in two rigid shelters. The fiber optic data bus interconnects the electronic equipments and bus controllers within each shelter. The MIFASS shelters must be capable of operating together when separated up to 50 m. A single point-to-point fiber optic link between shelters should provide for the required communications between bus controllers in each shelter. The number of operations modules (shelters) in the Marine Corps Tactical Air Operations Center-85 (TAOC-85) system is five. It may become cost-effective to use a data bus in place of point-to-point cabling for external shelter interconnections where the number of shelters in a center becomes appreciable.

2. A requirement in the MIFASS specification which is not practical for fiber optic cabling is the following: "Data cables for non-sheltered centers shall be made in three lengths (1, 2 and 10 m) and shall be capable of being connected together in order to span distances up to 100 m." Using ten such 10-m cables to span 100 m would introduce an additional 9 dB of connector losses to that link or bus which is in excess of any optical power margin for any bus system investigated. A fiber optic compatible alternative to this requirement needs to be found.

3. Closely related to the above problem is another caused by the parallel nature of the star coupler configuration. In estimating the quantity of fiber optic cable for each particular bus configuration, an average of 20 m was used for each user. However, large variations may exist from user to user. The equipments housed within shelters are interconnected by a set of relatively short cables. When the equipments are removed from the shelter to be deployed in bunkers, buildings, tents, etc., the shorter shelter cables must be replaced by longer cables to accommodate the new configuration. Variations in cable length and number of connectors affect the fiber optic path attenuation dramatically. Assume a group of 32 users strung out in a straight line each separated by 20 m. The two extreme users are separated from each other by 620 m. In this case, centrally locating the fiber optic star coupler means that the lengths of cable required between coupler and user vary from 10 meters to 310 meters. This problem requires a configuration study to determine the optimum method of interconnection.

B. BUS PROTOCOLS

1. The requirement to make maximum use of existing data bus architectures and protocols led to the investigation and identification of MIL-STD-1553 and MIL-G-85013 as the primary candidates for the data bus design. MIL-STD-1553 is presently being converted to a fiber optic bus standard operating at 1 Mb/s. Significantly less effort is required to convert MIL-STD-1553 to a fiber optic bus standard operating at 10 Mb/s than conversion of MIL-G-85013. The two most important modifications required to these specifications are as follows. First, the transmission rate of 1 Mb/s needs to be increased to 10 Mb/s, which affects a number of timing parameters. These parameters include terminal response times, terminal time outs, rise and fall times, etc. Second, the 5-bit terminal address field of the command and status words which can presently accommodate only 32 addresses need to be increased to 8 bits to accommodate 256 addressees.

Manufacturers of integrated circuits have developed high-speed LSI encoder-decoder bus interface chips which provide many of the requirements of MIL-STD-1553. A similar chip operating at 10 Mb/s will result in significant size, weight and cost reduction to further enhance use of a modified MIL-STD-1553.

2. Although distributed processing and distributed control is not specifically called for in the MIFASS specification, it can provide many advantages in a military environment particularly with regard to mobility and survivability. The Marine Corps Command-Control Center's complement of microcomputers, intelligent display terminals, and shared memory contains a decentralized system which is well suited to distributed processing and control. A distributed processing and control system could be designed which would be completely fail-safe. Upon failure of any equipment, the system could automatically reconfigure itself

to permit other units to perform the failed units' function. An investigation to determine the specific benefits of distributed processing for the MIFASS system could prove to be beneficial. An investigation of distributed control for the fiber optic data bus in place of single or dual bus controllers should be considered.

C. DEVELOPMENTAL RISK AREAS

The development risk associated with each of the major fiber optic components of the candidate systems is shown in Table 9. Candidate system IX which is considered the optimum system from a performance/cost standpoint contains the following moderate developmental risk fiber optic components.

1. Single Fiber Multiple Access Couplers

A number of manufacturers are presently producing developmental single fiber multiple access couplers with up to 32 input/output ports. NOSC has procured some developmental single fiber star couplers which are presently being evaluated. The optimum design identified in this report can be implemented with 8-port or 16-port couplers as easily as with 32-port couplers without any appreciable effect on the design or performance of the system.

A number of manufacturers are reporting excess losses of only 1.5 dB and port-to-port variations of ±1 dB for their single fiber multiple access couplers. These claims should be substantiated by evaluation of a number of single fiber star couplers in order to reduce the moderate risk presently associated with these components.

2. Single Fiber Connectors

Because reliable single fiber connectors are required for military applications of fiber optics, considerable work is being done to this end by all branches of the military service. In addition to the core-to-core fiber alignment problem, the tactical field environment introduces a number of conditions which the connector interface must be protected against. Militarized single fiber connectors are not presently available but are expected to be available for the MIFASS application in the near future. Single fiber connectors are therefore presently considered a moderate risk item.

3. Transmitter and Receiver Components

The LED and ILD source diodes and the PIN and ADP detector diodes are the critical components of the transmitter/receiver fiber optic modules. The operating life of the ILD (10^4 hr) is rapidly approaching that of the LED (10^5 hr). The operating life does not appear to be a major problem any longer. The transmitter/receiver modules require use of hermetically sealed LED, ILD, PIN, and ADP environment. At present no hermetically sealed fiber optic source or detector components exist. A substantial effort is required by component manufacturers to produce these militarized components.

Table 9. Developmental risk of candidate bus systems.

COMPONENT	CANDIDATE SYSTEM I		CANDIDATE SYSTEM VI		CANDIDATE SYSTEM VIII		CANDIDATE SYSTEM IX	
	QTY	RISK	QTY	RISK	QTY	RISK	QTY	RISK
STAR COUPLERS			1	MODERATE	8	MODERATE	8	MODERATE
T COUPLERS	256	MODERATE						
TDM/FDM MUX UNITS			40	LOW				
BIFURCATION DEVICE	386	MODERATE			264	MODERATE		
INJECTION LASER DIODE XMTR	258	MODERATE						
LED DIODE XMTR			586	LOW	264	LOW	264	LOW
PIN PHOTODIODE RCVR			586	LOW				
AVALANCHE PHOTODIODE RCVR	258	MODERATE			264	MODERATE	264	MODERATE
SINGLE FIBER CABLE INCLUDING CONNECTORS	5.1 Km	MODERATE	10.2 Km	MODERATE	5.1 Km	MODERATE	10.2 Km	MODERATE
		MODERATE		LOW/ MODERATE		MODERATE		LOW/ MODERATE

CATEGORIES:
- NO RISK
- LOW RISK
- MODERATE RISK
- HIGH RISK

X. SUMMARY AND CONCLUSIONS

This study and report show that it is feasible to use a fiber optic data bus to interconnect the shelter equipments of a tactical Marine Corps Command-Control System. A moderate development risk is associated with the single fiber cable connectors, star couplers, and militarized source and detector diodes. The functional requirements for such a system in the post-1980 era have been delineated using typical data bus requirements of the MIFASS system. The study has further identified the Command-Response Mode of MIL-STD-1553A and the Polled-Contention Mode of MIL-G-85013 with minor modifications as compatible with the throughput and protocol requirements of the fiber optic data bus. Representative implementations of a number of possible bus configurations were considered using state-of-the-art fiber optic multiple access couplers, optical sources and detectors.

Using system analysis techniques, one candidate was selected as the optimum design by virtue of its highest performance rating, lowest cost, and low/moderate developmental risk. The characteristics and unique features of the fiber optic system are:

- Lightweight single fiber technology
- Efficient state-of-the-art transmissive star couplers
- Passive couplers, no repeaters, no serial chains
- Sufficient link optical power margins
- High availability, survivability and flexibility
- Ease of modular expansion from the smallest to the largest shelter
- Graceful degradation from normal to back-up operation
- Weight and volume reductions contribute to ease of transportability
- Nonradiating property of fiber optics cable together with physical security of limited access shelter area contribute to a secure cable system
- Fiber optic data bus is EMI/EMP immune.

XI. RECOMMENDATIONS

This report provides a baseline fiber optic data bus design for a tactical Marine Corps Command-Control System application. In addition, it identifies a number of design-related developmental risk areas. In order to reduce the risk, it is recommended that additional related efforts be initiated in FY79 in the following areas:

- Design and build a demonstration fiber optic data bus to interconnect typical equipments used in a tactical Marine Corps Command-Control shelter system such as computers, peripherals, display consoles, and communications inputs and outputs. This design should incorporate state-of-the-art fiber optic components, optimum configuration, controller schemes, and protocols developed from the FY78 and FY79 efforts.

- Investigate the feasibility of a failsafe distributed control system for the fiber optic data bus system.
- Conduct a configuration study to determine the best method of interconnection of nonsheltered centers. Determine optimum location for the star coupler and optimum method of building up cable segments to compensate for cable length variations of a few meters up to 200 m required between equipment.
- Identify alternate suppliers of militarized single fiber multiple access star couplers, single fiber connectors, light emitting diodes, injection laser diodes, and detector photodiodes which have applicability to the fiber optic data bus.

APPENDIX A

TYPICAL VENDOR SPECIFICATION SHEETS

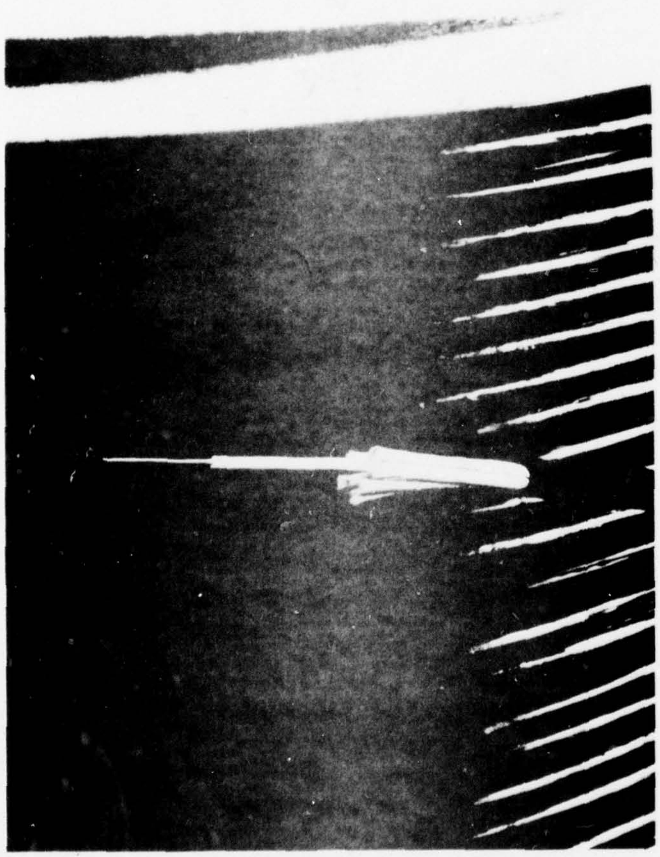
FOR

STATE-OF-THE-ART

FIBER OPTIC COMPONENTS

SINGLE FIBER STRENGTHENED CABLE

Single Fiber Strengthened Cable, Type S1, is a small diameter, strong, flexible, lightweight cable design, suitable for many general purpose single channel fiber optic data links, such as intravehicle and intrabuilding, installation in conduit or cabling ducts, incorporation in multipurpose cables and for limited field use. The cable consists of a single optical fiber surrounded by six Kevlar® strength members, and encapsulated in an extruded plastic jacket. This cable is available with Plastic Clad Silica, Glass Step Index, or Glass Graded Index Fiber.



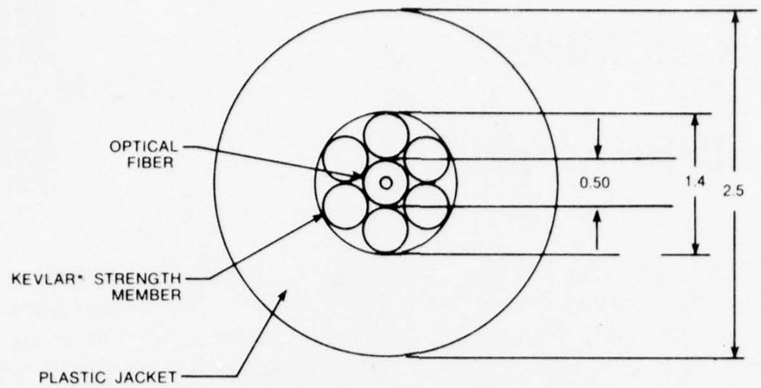
OPTICAL

Optical characteristics depend on type of optical fiber used. Attenuation and type numbers are listed on the reverse side.

MECHANICAL	NOMINAL
Fiber Core Diameter (PS, GS-GG)	125, 50 μm
Jacketed Fiber Diameter	500 μm
Cable Diameter	2.5 mm
Weight	6 kg/km
Tensile Strength (2 m gauge length)	45 kgf
Minimum Bending Radius	2.5 cm

This specification is for a developmental product, subject to change without notice.

ITT



All dimensions in millimeters

CONFIGURATIONS

CABLE TYPE NUMBER	OPTICAL FIBER DESCRIPTION	FIBER TYPE NUMBER	ATTENUATION (dB/km)
			(.79μm)
S-40-PS-(1)	Plastic Clad	PS-05-35	40
S-25-PS-(1)	Silica Fiber	PS-05-20	25
S-10-PS-(1)		PS-05-10	10
			(.85μm)
S-20-GS-(1)	Glass Step	GS-02-12	20
S-10-GS-(1)	Index Fiber	GS-02-8	10
S-6-GS-(1)		GS-02-5	6
			(.85μm)
S-20-GG-(1)	Glass Graded	GG-02-12	20
S-10-GG-(1)	Index Fiber	GG-02-8	10
S-6-GG-(1)		GG-02-5	6

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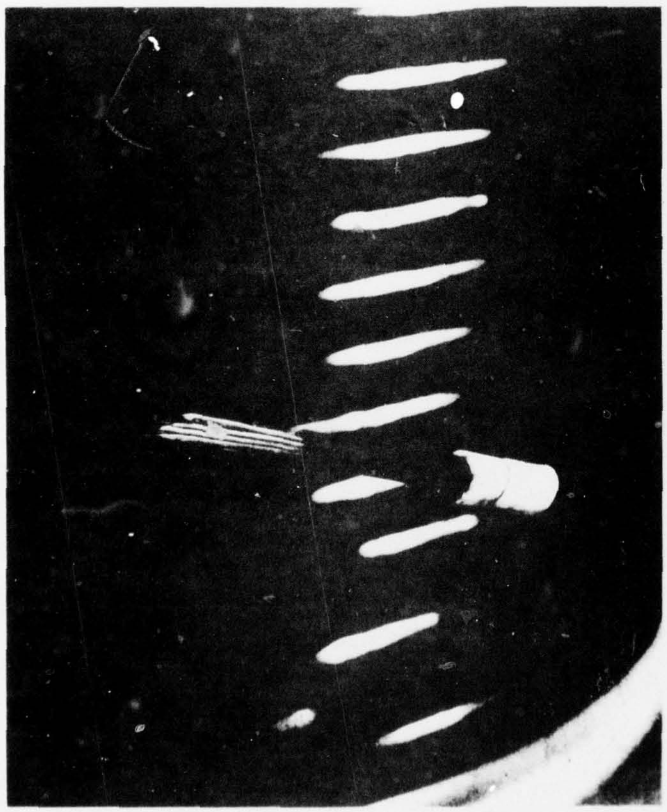
7635 Plantation Rd., Roanoke, Va. 24019. Telephone (703) 563-0371

EXTERNAL STRENGTH MEMBER HEAVY DUTY OPTICAL FIBER CABLE

Type ESM optical fiber cable is designed for use in single fiber per channel transmission systems which require high cable strength and crush resistance. The cable contains seven optical fibers in an extruded polyurethane jacket surrounded by helically laid Kevlar® strength members and another extruded polyurethane jacket. This design provides ease of strength member and optical fiber termination, high strength, and abrasion resistance. Optical fibers may be Plastic Clad Silica, Glass Step Index or Glass Graded Index.

External Strength Member cable is highly flexible and kink resistant, and therefore ideally suited for use in conduit, cable trays and a variety of intravehicle applications.



SPECIFICATIONS

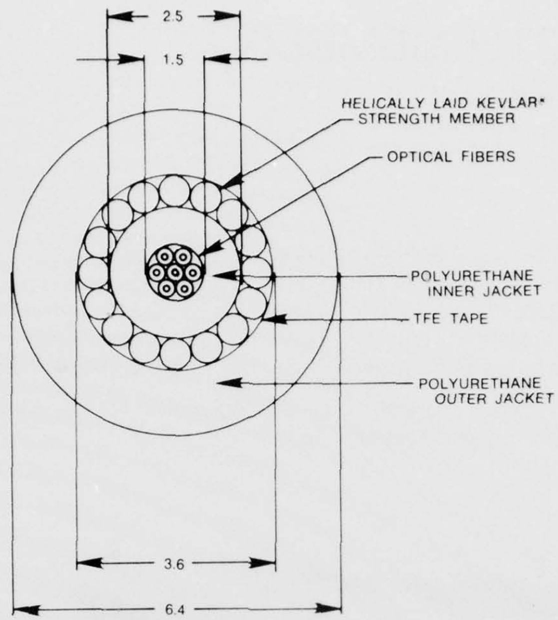
OPTICAL

Optical characteristics depend on the type of optical fiber used. Attenuation and type numbers are listed on the reverse side.

MECHANICAL	NOMINAL
Number Of Fibers	7
Fiber Core Diameter (PS, GS-GG)	125, 50 μm
Jacketed Fiber Diameter	500 μm
Cable Diameter	6.0 mm
Weight	30 kg/km
Tensile Strength (2m gauge length)	100 kgf
Minimum Bending Radius	5.0 cm

This specification is for a developmental product, subject to change without notice.

ITT



All dimensions in millimeters

CABLE TYPE NUMBER*	OPTICAL FIBER DESCRIPTION	FIBER TYPE NUMBER	ATTENUATION (dB/km)
			(.79μm)
ESM-40-PS-(7)	Plastic Clad	PS-05-35	40
ESM-25-PS-(7)	Silica Fiber	PS-05-20	25
ESM-10-PS-(7)		PS-05-10	10
			(.85μm)
ESM-20-GS-(7)	Glass Step	GS-02-12	20
ESM-10-GS-(7)	Index Fiber	GS-02-8	10
ESM-6-GS-(7)		GS-02-5	6
			(.85μm)
ESM-20-GG-(7)	Glass Graded	GG-02-12	20
ESM-10-GG-(7)	Index Fiber	GG-02-8	10
ESM-6-GG-(7)		GG-02-5	6

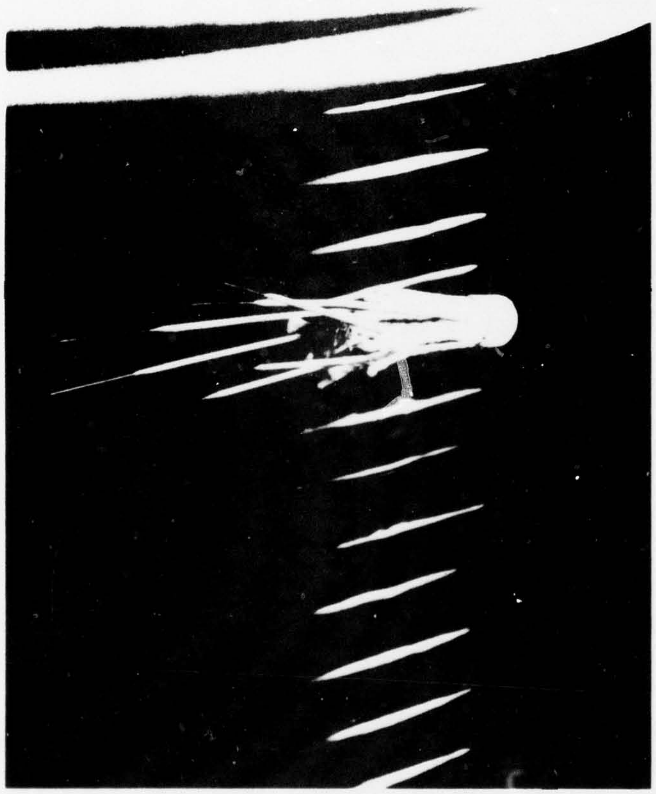
*Standard External Strength Member (ESM) cables contain seven fibers. ( ) indicates number of fibers guaranteed operational in the cable. Up to 19 fibers are available in this cable configuration on a custom order basis.

ELECTRO-OPTICAL PRODUCTS DIVISION ITT
7635 Plantation Rd., Roanoke, Va. 24019. Telephone (703) 563-0371

INTERNAL STRENGTH MEMBER HEAVY DUTY OPTICAL FIBER CABLE

Internal Strength Member, Type ISM optical fiber cable is designed for use in data transmission systems which require a high strength cable having good crush resistance. The cable contains six optical fibers helically laid around a central load bearing Kevlar® strength member. An extruded polyurethane jacket provides abrasion resistance and environmental protection. It is available with Plastic Clad Silica, Glass Step Index, or Glass Graded Index Fibers.

Type ISM is highly flexible and kink resistant, and therefore ideally suited for use in conduit, cable trays and a variety of intravehicle applications.



OPTICAL

Optical characteristics depend on type of fiber used. Characteristics and cable type numbers are listed on the reverse side.

MECHANICAL	NOMINAL
Number Of Fibers	6
Fiber Core Diameter (PS, GS-GG)	125, 50 μm
Jacketed Fiber Diameter	500 μm
Cable Diameter	6.0 mm
Weight	30 kg/km
Tensile Strength (2m gauge length)	100 kgf
Minimum Bending Radius	5.0 cm

This specification is for a developmental product, subject to change without notice.

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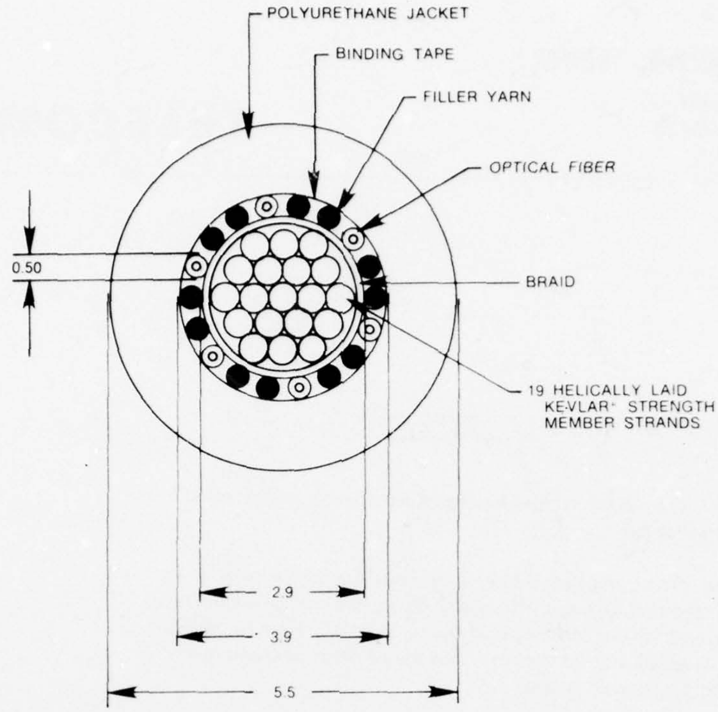

All dimensions in millimeters

CABLE TYPE NUMBER*	OPTICAL FIBER DESCRIPTION	FIBER TYPE NUMBER	ATTENUATION (dB/km)
			(.79μm)
ISM-40-PS-(6)	Plastic Clad	PS-05-35	40
ISM-25-PS-(6)	Silica Fiber	PS-05-20	25
ISM-10-PS-(6)		PS-05-10	10
			(.85μm)
ISM-20-GS-(6)	Glass Step	GS-02-12	20
ISM-10-GS-(6)	Index Fiber	GS-02-8	10
ISM-6-GS-(6)		GS-02-5	6
			(.85μm)
ISM-20-GG-(6)	Glass Graded	GG-02-12	20
ISM-10-GG-(6)	Index Fiber	GG-02-8	10
ISM-6-GG-(6)		GG-02-5	6

* Standard Internal Strength Member (ISM) cable contains six fibers. ( ) indicates number of fibers guaranteed operational in the cable. Up to 18 optical fibers are available in this cable configuration on a custom order basis.

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OPTELECOM, INC.
15940 Shady Grove Rd.
Gaithersburg, Md. 20760
301-948-4232

OPTICAL TELECOMMUNICATIONS

MAY 15, 1978

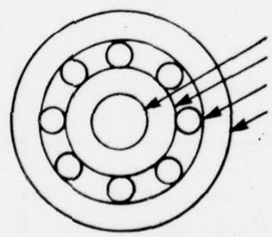
FIBER OPTIC CABLE–TYPE CSK

Type CSK strengthened fiber is designed for digital or analog optical communication

Type CSK strengthened fiber is designed for digital or analog optical communication channels. The cable contains a buffered core with one or more optical fibers. Kevlar* strength members are wrapped around the core, and the whole in encased in a protective plastic jacket.

Type CSK cable is well suited for drawing through ducts or other semiprotected environments. This cable is flexible, waterproof and economical.

*Dupont trade mark



FIBER CHARACTRISTICS

Any of the types of optical fibers specified in the optical fiber data sheet may be incorporated into this strengthened fiber optic cable. The attenuation through the cable depends on the grade of fiber employed.

CABLE CHARACTERISTICS

	CSK–125	CSK–90
Overall diameter	0.125 inch	0.090 inch
Number of fibers	1 to 7	1 to 7
Tensile strength	120 lbs.	120 lbs.
Minimum Safe Bend Radius	1 inch	1 inch
Available Length	up to 10 Km	

OPTELECOM, INC.
15940 Shady Grove Rd.
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301-948-4232

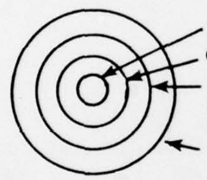
OPTICAL TELECOMMUNICATIONS

MAY 15, 1978

FIBER OPTIC CABLE–TYPE CSG

Type CSG ruggedized fiber is designed for analog or digital optical communication channels. The cable contains a buffered core encased in a strong fiberglass/epoxy matrix, as shown in the diagram. This design permits connectors to be epoxied directly to the strength member to provide reliable, high strength terminations.

Type CSG cable is well suited for burial in the ground on a bed of sand, or for any other land or marine application where it will not be bent over a sharp edge at full stress.



FIBER CHARACTERISTICS

Any of the types of optical fibers specified in the optical fiber data sheet may be incorporated into this ruggedized fiber optic cable. The attenuation through the cable depends on the grade of fiber employed.

CABLE CHARACTERISTICS

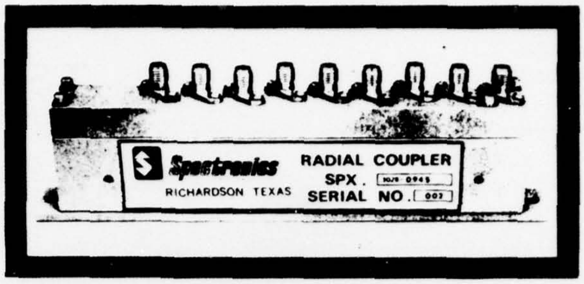
	CSG–125	CSG–90	CSG–75
Overall diameter	0.125 inch	0.090 inch	0.075 inch
Number of fibers	1 to 7	1 to 7	1
Tensile strength	400 lbs.	300 lbs.	300 lbs.
Minimum Safe Bend Radius	1.5 inch	1 inch	1 inch
Available Length		up to 10 Km	

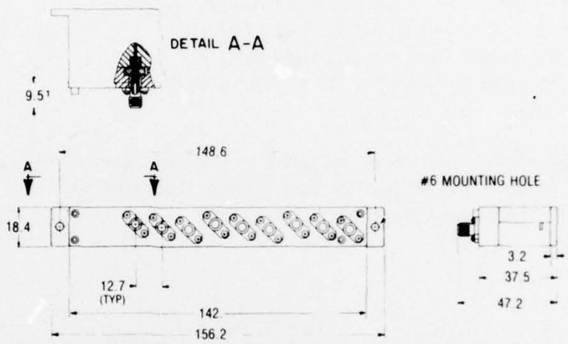
FIBER OPTIC RADIAL COUPLER

FEATURES
- **Completely passive**
- **Two fiber optic rod sizes available**
- **Up to 32 ports per coupler**
- **Low internal loss**
- **Standard SMA type connectors for low coupling loss**

DESCRIPTION
The SPX 3028 radial coupler is a passive coupler used for distributing an optical signal in a fiber optics data bus transmission system. The signal is received at one port and distributed evenly into each of the other ports, providing a half-duplex optical data transmission path. The device uses square fiber construction providing uniform signal distribution in a compact rugged unit. Connectors are compatible with the Amphenol 905 precision series.

MAXIMUM RATINGS
Storage and operating temperature:
−65° to + 125°C





Note 1: Fiber to connector dimension

All dimensions in millimeters.

OPTICAL CHARACTERISTICS

PARAMETER	DEFINITION	SYMBOL	MIN	TYP	MAX	UNITS
Excess loss	$10 \log \left[\frac{\text{power out}}{\text{power in}}\right]$	EL		4	5.5	dB
Optical Signal range	$10 \log (P_o MAX/P_o MIN)$	OSR		1	1.5	dB
Numerical aperture		NA	.44			
Mass				565		g

ORDERING INFORMATION SPX-3028-XXY

The dash-numbering system is used to specify the number of ports desired and the F.O. rod size in millimeters. The first two digits of the three digit dash number specify the number of ports as shown in the table below. The last digit represents the rod size as coded below.

No. of Ports	XX
4	04
9	09
16	16
32	32

Rod Size	Y
.64 mm	2
1.14 mm	1

Example: A 9 port coupler with .64 mm bundles is designated SPX-3028-092.

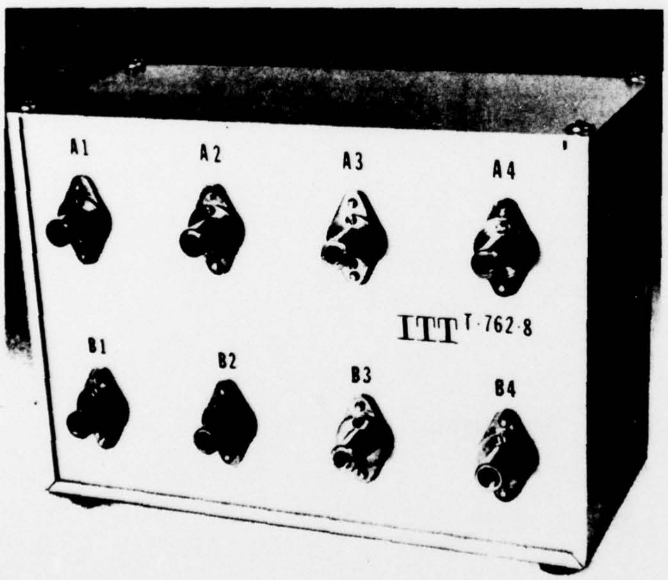
Spectronics
INCORPORATED

OPTICAL FIBER COUPLERS

ITT optical couplers have been developed for low-loss drop/insert, duplexing, branching, monitoring, mixing, and multiplexing applications in single-fiber control and communication systems. These star and directional couplers can be used in networks where many terminals communicate with each other and/or with a central point over a single high-bandwidth fiber optic data bus, or over several spatially-multiplexed optical fibers.

Both plastic-clad silica (PCS) fiber-compatible and glass-on-glass fiber-compatible couplers are available. PCS couplers include MxM transmission star optical couplers, M-port reflection star optical couplers, three-port optical directional couplers, and hybrid optoelectronic three-port directional couplers in which the tapoff port is a PIN photodiode. Glass-on-glass fiber-compatible couplers for use with step- or graded-index fiber include optical and opto-electronic directional couplers, as well as directional wavelength-duplexing couplers which allow bidirectional, wavelength-multiplexed transmission over a single optical fiber. Fiber pigtails which can be supplied with factory-installed connectors provide optical interface to all couplers.

These couplers, when configured with the appropriate light source, fiber, and detector, enable the user to design heretofore impossible system architectures that take advantage of the inherent features of optical fibers. These features include wide bandwidth, low loss, immunity from electromagnetic interference, radio frequency interference and electromagnetic pulse, along with small cable size, high transmission security, negligible crosstalk, ground isolation, and spark and short circuit protection.



FEATURES

- Low excess loss
- Single-fiber technology
- Up to 19-port transmission stars
- High isolation
- PCS or glass-on-glass fiber compatibility
- Wavelength duplexing

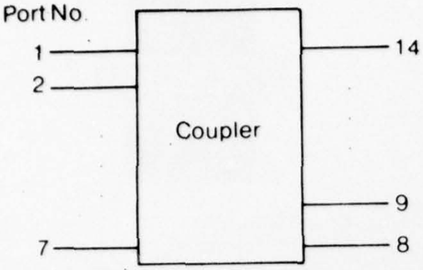
APPLICATIONS

- Telecommunications
- Interactive data processing
- Data busing
- Multi-user CATV
- Secure communications
- Fly-by-fiber systems
- Fiber-guided vehicles
- High-bandwidth multiple-access links
- Laser/LED/avalanche photodiode power monitoring for linearization, AGC, or fault detection purposes

This specification is for a developmental product, subject to change without notice.

ITT

TRANSMISSION STAR COUPLERS (PCS-COMPATIBLE§)



SPECIFICATIONS†

Insertion Loss Matrix for 7x7-port coupler

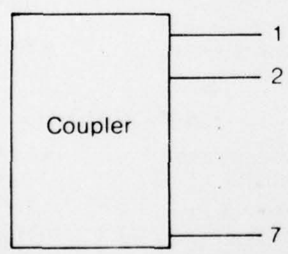
$$\left(\begin{array}{ccc|ccc} P_{11} & \cdots & P_{17} & P_{18} & \cdots & P_{1,14} \\ \vdots & & \vdots & \vdots & & \vdots \\ P_{71} & \cdots & P_{77} & P_{78} & \cdots & P_{7,14} \\ \hline P_{81} & \cdots & P_{87} & P_{88} & \cdots & P_{8,14} \\ \vdots & & \vdots & \vdots & & \vdots \\ P_{14,1} & \cdots & P_{14,7} & P_{14,8} & \cdots & P_{14,14} \end{array}\right)$$

NOMINAL

$$\left(\begin{array}{c|c} \begin{array}{l} -35 \text{ if ports 8-14 are index-matched to output fibers} \\ -28 \text{ if not} \end{array} & -12 \pm 1 \\ \hline -12 \pm 1 & \begin{array}{l} -35 \text{ if ports 1-7 are index-matched to output fibers} \\ -28 \text{ if not} \end{array} \end{array}\right) \text{dB}$$

Port pigtail dimensions	
core diameter	127 μm or 203 μm (specify)
jacket diameter	500 μm

REFLECTION STAR COUPLERS (PCS-COMPATIBLE)



SPECIFICATIONS†

Insertion Loss Matrix for 7-port coupler

$$\begin{pmatrix} P_{11} & \cdots & P_{17} \\ \vdots & & \vdots \\ P_{71} & \cdots & P_{77} \end{pmatrix}$$

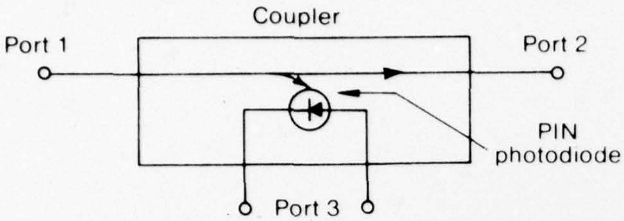
NOMINAL

$P_{mn} = -14 \pm 1$ dB

Port pigtail dimensions	
core diameter	127μm
jacket diameter	500 μm

Matrix elements Pxy in dB represent optical power level at port X in watts compared to input power in port Y in watts. ($P_{xy} = 10 \log_{10} \frac{P_x}{P_y}$). For notes see back cover.

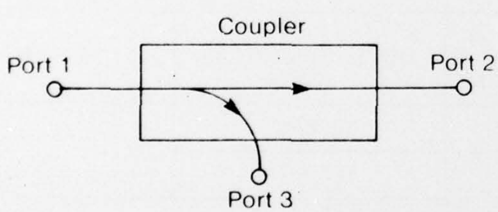
THREE-PORT OPTOELECTRONIC DIRECTIONAL COUPLER



SPECIFICATIONS[†]	**PCS-COMPATIBLE NOMINAL**	**STEP/GRADED COMPATIBLE NOMINAL**
Insertion Loss Matrix		
$\begin{pmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \\ H_{31} & H_{32} \end{pmatrix}$	$\begin{pmatrix} 14 & 4 \\ 4 & 14 \\ \hline 0.2 & 0.01 \end{pmatrix}$ dB, A/W	$\begin{pmatrix} 14 & 1 \\ 1 & 14 \\ \hline 0.5 & 0.05 \end{pmatrix}$ dB, mA/W
Port 1, 2 pigtail dimensions		
core diameters	127 μm	55 μm
cladding diameters	300 μm	127 μm
jacket diameters	500 μm	500 μm

PIN Characteristics[§§]

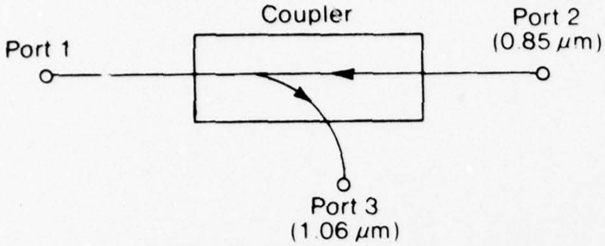
capacitance	< 10 pF
bias voltage required	−10V
noise equivalent power [(λ, f, Δf) = (770 nm, 100 Hz, 6 Hz)]	6×10^{-14} W/√Hz
dark current	2.5 nA



SPECIFICATIONS[†]	**PCS-COMPATIBLE NOMINAL**	**STEP/GRADED-COMPATIBLE TIME-DOMAIN REFLECTOMETER (TDR) NOMINAL**	**STEP/GRADED-COMPATIBLE MONITOR NOMINAL**
Insertion Loss Matrix			
$\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}$	$\begin{pmatrix} 14 & 4 & 4 \\ 4 & 14 & 17 \\ 4 & 17 & 14 \end{pmatrix}$ dB	$\begin{pmatrix} 14 & 5 & 6 \\ 5 & 14 & 40 \\ 4 & 40 & 30 \end{pmatrix}$ dB	$\begin{pmatrix} 14 & 1 & 30 \\ 1 & 14 & 40 \\ 30 & 40 & 30 \end{pmatrix}$ dB
Port pigtail dimensions			
core diameters	127 μm or 203 μm	55 μm	55 μm
cladding diameters	300 μm	127 μm	127 μm
jacket diameters	500 μm	500 μm	500 μm

For notes see back cover.

THREE-PORT WAVELENGTH-DUPLEX DIRECTIONAL COUPLER (STEP/GRADED COMPATIBLE)



SPECIFICATIONS†

Insertion Loss Matrix

$$\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}$$

NOMINAL AT 0.85 μm

$$\begin{pmatrix} 14 & 1.5 & 10 \\ 1.5 & 14 & 40 \\ 10 & 40 & 30 \end{pmatrix} \text{dB}$$

NOMINAL AT 1.06 μm

$$\begin{pmatrix} 14 & 7 & 3 \\ 7 & 14 & 40 \\ 3 & 40 & 30 \end{pmatrix} \text{dB}$$

Port pigtail dimensions (at all wavelengths)

core diameter	55 μm
cladding diameter	127 μm
jacket diameter	500 μm

COUPLER TYPE NUMBERS

COUPLER	CONNECTOR ON PIGTAILS	FIBER PIGTAIL CORE DIAMETER: PCS 203 μm	PCS 127 μm	GLASS-ON-GLASS 55 μm	NOTES
TRANSMISSION STAR (M × M-Port)	YES	T-760-M	T-762-M	DEVELOPMENTAL	M = 2 – 19*
	NO	T-761-M	T-763-M		
REFLECTION STAR (N-Port)	YES	-----------	T-767-N	DEVELOPMENTAL	N = 3 – 19*
	NO	-----------	T-768-N		
THREE-PORT OPTICAL TDR DIRECTIONAL COUPLER	YES	T-778	T-780	T-784	
	NO	T-779	T-781	T-785	
THREE-PORT OPTICAL MONITOR DIRECTIONAL COUPLER	YES	-----------	-----------	T-786	
	NO	-----------	-----------	T-787	
THREE-PORT WAVELENGTH DUPLEX DIRECTIONAL COUPLER	YES	-----------	-----------	T-788	
	NO	-----------	-----------	T-789	
THREE-PORT OPTOELECTRONIC DIRECTIONAL COUPLER	YES	-----------	T-782	T-790	
	NO	-----------	T-783	T-791	

§ Glass-on-glass-compatible 55 μm core PCS star couplers are under development

† *All losses measured under full-NA port illumination*

§§ PIN characteristics quoted are typical for the HP-5082-4207 PIN photodiode and apply to both *optoelectronic coupler types. Other PINs will be supplied on request*

* CONTACT ITT FOR SPECIFIC OPTICAL PARAMETERS

6/78

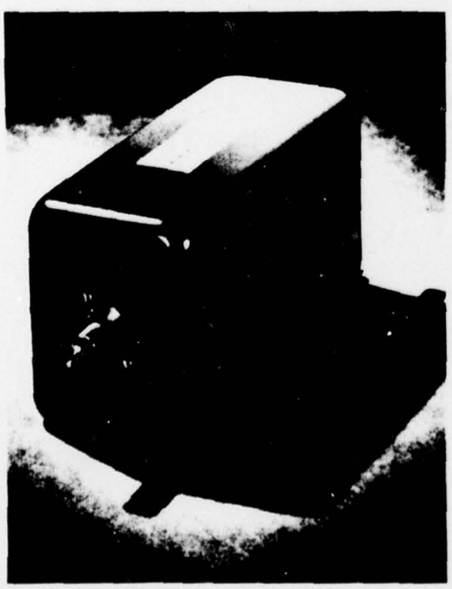
ELECTRO-OPTICAL PRODUCTS DIVISION ITT

7635 Plantation Rd., Roanoke, Va. 24019. Telephone (703) 563-0371

OPTICAL FIBER DIGITAL TERMINALS MODEL 2-D

The Model 2-D is a digital fiber optic transmission system capable of data rates of 100 kb/s to 20 Mb/s over several kilometers of ITT optical fiber cable. Inputs and outputs are TTL compatible, with amplitude regenerated data out. In addition, an analog signal output is provided for received signal monitoring, or other special purposes. Model 2-D transmitter employs a high brightness LED, with four switch selectable LED drive settings (¼, ½, ¾, and maximum) for flexibility of optical output power. The receiver features an avalanche photodiode detector to maximize optical efficiency of the link. The design includes a hybridized high voltage power supply for the APD, with AGC controlled output voltage. Alternately, the receiver can be supplied with a PIN detector, when system requirements do not demand maximum receiver sensitivity.

The Model 2-D link is useful for a variety of applications where the dielectric properties of optical waveguide provide immunity to electromagnetic interference (EMI), electromagnetic pulses (EMP), and radio frequency interference (RFI). Other features are wide bandwidth, low cross talk, transmission security, and no spark or short circuit hazards.



	NOMINAL
Upper Bit Rate Cutoff	20 Mb/s
Lower Cutoff (10% Analog Droop)	500 Hz square wave
TRANSMITTER	
Input Impedance	50 Ω, or 4 TTL loads
Maximum Input Signal Level	5 volts
Power Supply	5 ± 0.25 VDC at 300 ma max.
Optical Output Power (Max LED Drive)	
With ITT type GG-02 graded index fiber termination	30 μw peak (TTL high)
With ITT type GS-02 step index fiber termination	60 μw peak (TTL high)
RECEIVER	
Output Impedance	
Digital output	50 Ω
Analog output	600 Ω
Analog output signal level	3 V P-P nom.
Digital Output	TTL Line Driver
Power Supplies	+5 ± 0.25 VDC at 75 ma max. +8 to +18 VDC at 100 ma max. −8 to −18 VDC at 75 ma max.
Optical Sensitivity at 10^{-8} BER	6 nW peak (TTL high)
Optical Dynamic range	20 dB
Rise/Fall time	
Digital output	8 ns max.
Analog output (for negligible fiber dispersion)	20 ns max.

This specification is for a developmental product, subject to change without notice.

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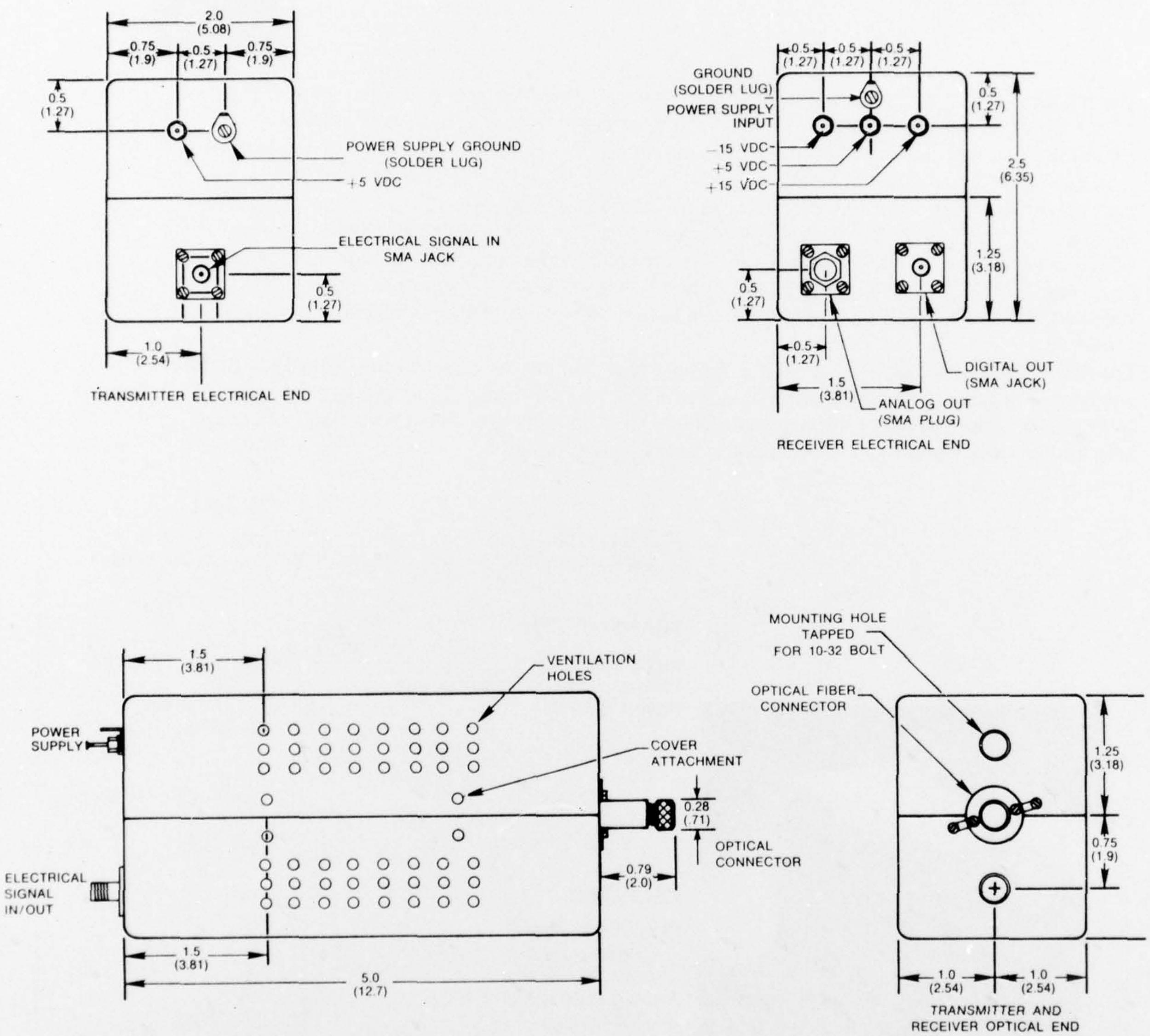

TRANSMITTER AND RECEIVER MECHANICAL

All dimensions in inches (centimeters)

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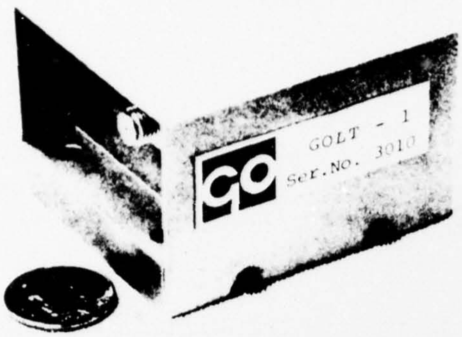
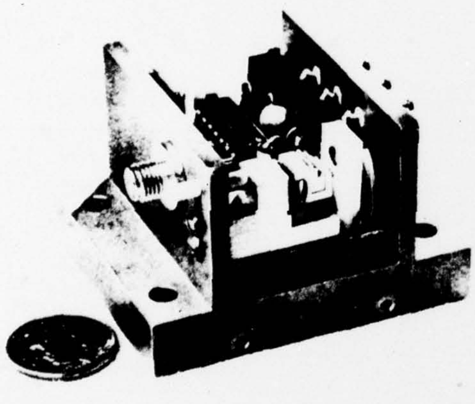
LASER OPTICAL TRANSMITTERS





MODEL GOLT-1

- ☐ Bias stabilization scheme: Optical and thermal feedbacks.
- ☐ Wavelength: 830 nm nominal, can be 800 nm to 870 nm by special order.
- ☐ Operating voltage range: −7 to −15 volts.
- ☐ Total operating current to maintain 5 mW light output per mirror: Less than 1.2 Amp.
- ☐ Operating case temperature range: −50° to +70° C.
- ☐ Frequency response: 20 Hz to 500 MHz.
- ☐ RF input: Less than 1 volt peak-to-peak to obtain 70% modulation.
- ☐ Input impedance: 50Ω or 75Ω.
- ☐ Harmonic distortion:
  Better than −40dB second harmonic and −50dB third harmonic at 70% modulation biased at 2.5 mW output power per mirror.
- ☐ Light output stability: Better than 0.1% over the entire operating current and temperature range.
- ☐ Storage temperature: −55° C to 100° C.
- ☐ Reliability: Better than 10^5 hours at 25° C.
- ☐ Passivation: Special coating on laser mirrors for usual ambient operation.

MODEL GOLT-2

- ☐ Bias stabilization scheme: Optical feedback.
- ☐ Wavelength: 830 nm nominal, can be 800 nm to 870 nm by special order.
- ☐ Operating voltage range: −7 to −15 volts.
- ☐ Total operating current to maintain 5 mW light output per mirror: Less than 200 mA.
- ☐ Operating case temperature: −50° to +65° C.
  Operation at temperatures higher than 35° C for prolonged time is not recommended for reliability considerations.
- ☐ Frequency response: 20 Hz to 500 MHz.
- ☐ RF input: Less than 1 volt peak to peak to obtain 70% modulation.
- ☐ Input impedance: 50Ω or 75Ω.
- ☐ Harmonic distortion:
  Better than −40dB second harmonic and −50dB third harmonic at 70% modulation biased at 2.5 mW output power per mirror.
- ☐ Light output stability: Better than 0.1%.
- ☐ Storage temperature: −55° to 100° C.
- ☐ Reliability: Better than 10^5 hours at 25° C.
- ☐ Passivation: Special coating on laser mirrors for usual ambient operation.

MODEL GOLT-3

- ☐ Provided with 10 cm graded index optical fiber.
  Core diameter—62.5 to 90 micrometers.
  Fiber diameter—120 to 125 micrometers.
  Numerical aperture—0.2.
- ☐ Bias stabilization scheme: Optical and thermal feedbacks.
- ☐ Wavelength: 830 nm nominal, can be 800 nm to 870 nm by special order.
- ☐ Operating voltage range: −7 to −15 volts.
- ☐ Total operating current to maintain 5 mW light output per mirror: Less than 1.2 Amp.
- ☐ Operating case temperature range: −50° to +70° C.
- ☐ Frequency response: 20 Hz to 500 MHz.
- ☐ RF input: Less than 1 volt peak-to-peak to obtain 70% modulation.
- ☐ Input impedance: 50Ω or 75Ω.
- ☐ Harmonic distortion:
  Better than −40dB second harmonic and −50dB third harmonic at 70% modulation biased at 2.5 mW output power per mirror.
- ☐ Light output stability: Better than 0.1% over the entire operating current and temperature range.
- ☐ Storage temperature: −55° C to 100° C.
- ☐ Reliability: Better than 10^5 hours at 25° C.
- ☐ Passivation: Special coating on laser mirrors for usual ambient operation.

general optronics

375 Park Ave., New York, N.Y. 10022

3005 Hadley Rd., S. Plainfield, N. J. 07080

SPERRY UNIVAC
DEFENSE SYSTEMS

HYBRID FIBER OPTIC TRANSMITTER/RECEIVER MODULES

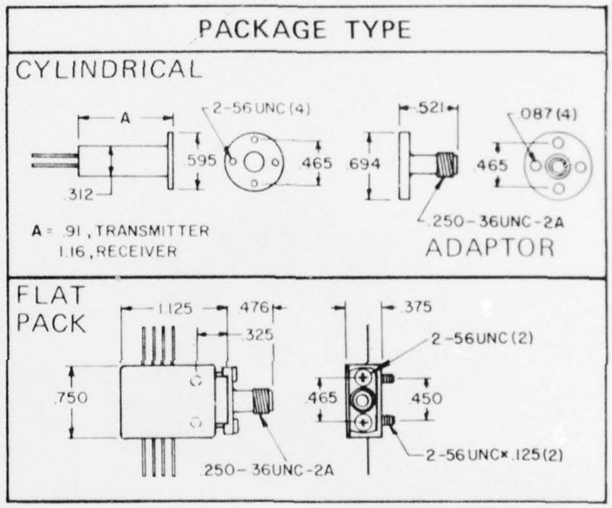
Sperry Univac Defense Systems has developed a line of militarized hybrid fiber optic digital modules compatible with U.S. Navy Standard 45 mil fiber optic bundle cable and connectors.

POINT-TO-POINT DIGITAL LINK (VARIABLE DATA RATE) MODULES

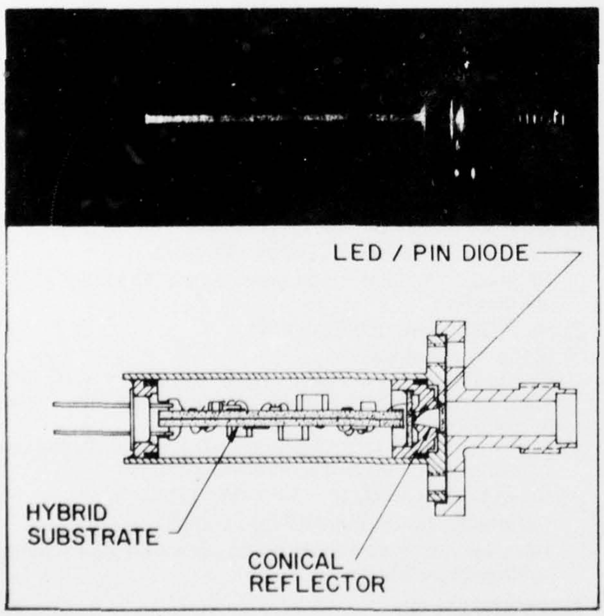
Variable data rates from 6 bits/sec to 20 Mbits/sec for point-to-point links are accommodated by these modules which feature a wide dynamic range (20 dB) and an automatic gain set. The automatic gain set adjusts the receiver gain for optimum reception of the optical signal. It automatically compensates for variable cable lengths, connector losses, and aging of the optical components. Response time of the AGC circuitry is a function of the minimum data rate and is factory adjustable to order.

DATA BUS RECEIVER MODULE

An alternative receiver design is the Data Bus Receiver Module. It provides similar performance characteristics using pulse amplitude limiting rather than automatic gain control for achieving wide dynamic range. This receiver accommodates wide variations in input power level which arise in multi-terminal data bus applications.



ALL DIMENSIONS IN INCHES



The optical emitter/detector is mounted at the base of a conical reflector which interfaces with the cable connector. Hybrid substrates contain the driver/receiver amplifier circuitry and are tailored to meet specific data link requirements. Standard modules for point-to-point and data bus applications are available from stock in cylindrical packages for panel mounting or flat packs for printed circuit card mounting.

An experimental 5 M bit/sec digital data link consisting of transmitter, receiver, connector adaptor, and 100 feet of high loss 400 dB/km fiber optic cable is available.

TRANSMITTER MODULE (PANEL MOUNT) P N 706298

Typical Performance:

Radiant Power Output	:	2 milliwatts total. 1 milliwatt into 25^{o} half angle cone. (Uncompensated for temperature)
Rise/Fall Time	:	20 nanoseconds.
Pulse Skew	:	4 nanoseconds.
Spectrum	:	918 nanometer. (28 nanometer bandwidth.)
Aperture	:	55 mils diameter.
Emission Uniformity	:	.5 min/max ratio.
Signal Input	:	TTL.
Power Source	:	5 volt, 100 ma average.
Package Type	:	Cylindrical (.336" diam. x .91" length.), wt = 11 grams

TRANSMITTER MODULE (FLAT PACK

Typical Performance:

Identical to P/N 7016298 except:

Radiant Power Output	:	1.5 milliwatts total. .75 milliwatts into 25^{o} half angle cone. (Features internal temperature compensation to stabilize RPO within ± 8% over -55^{o}C to +95^{o}C).
Package Type	:	Flat Pack. (.75" x 1.125" x .375").

RECEIVER MODULE (PANEL

Typical Performance:

*Optical Input	:	1 microwatt to 200 microwatts.
Data Rate	:	6 Hz to 5 MHz.
Pulse Width Variation	:	± 10 nanoseconds.
Jitter	:	5 nanoseconds.
Input Noise	:	.1 microwatt.
Gain Set Response Time	:	Optional (Factory Set 15 sec. max.).
Spectral Range	:	800 nanometers to 950 nanometers
Aperature	:	65 mils diameter.
Output Signal	:	TTL.
Power Input	:	± 5V at 35 ma each.
Package Type	:	Cylindrical (.336" diam. x 1.16" length). wt = 11 grams.

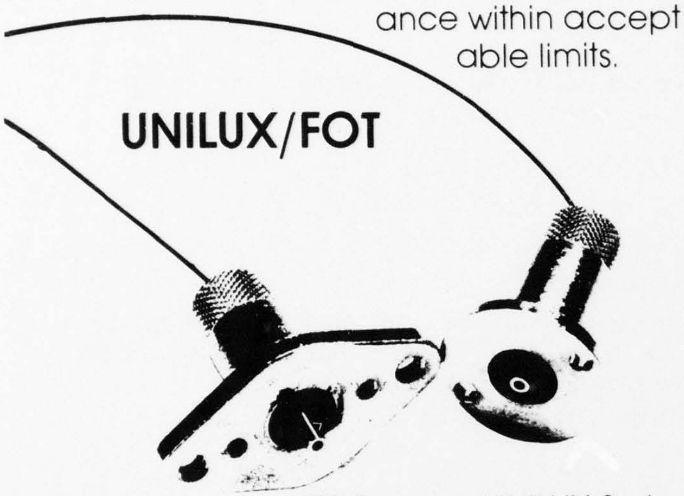
*Modifications to this receiver are available which allow the unit gain to be set externally with a single resistor, rather than by the automatic gain set. Usable dynamic range is about 6 dB (power) at a fixed gain setting within the overall limits of 1 microwatt to 200 microwatts input.

For further information contact Marc Shoquist or Bruce Lindell, Sperry Univac Defense Systems, UNIVAC Park, P.O. Box 3525, St. Paul, Minnesota 55165, (612) 456-2222.

UDS 117650

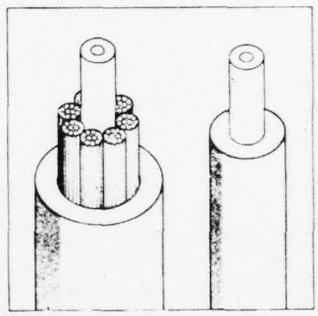
A PRACTICAL SOLUTION TO COUPLING SINGLE OPTICAL FIBERS

Maintaining low coupling losses with single optical fibers is considerably more difficult than with fiber bundles. Coaxial alignment, angular alignment, fiber end gap and optical end preparation must be tightly controlled to keep performance within acceptable limits.



ITT Cannon UNILUX Series connectors solve the fiber positioning problems with a precision ferrule that provides necessary optical alignments and protects the fiber. Fiber ends are accurately, repeatably positioned to maximize coupling efficiency, yet protect the interfaces from scratching and chipping that could cause signal degradation. Termination kits are available to ensure that fiber ends are chip-free, flat and perpendicular to the fiber centerline. Fiber-to-fiber coupling losses are typically 2 dB, with losses as low as 1 dB possible.

ITT Cannon UNILUX Series connectors may be used with single fiber cables from most manufacturers. The UNILUX/FOS connector couples single fibers in strengthened cables, while the UNILUX/FOT couples single fibers in unstrengthened cables. Both connector types may be used for fiber-to-fiber or fiber-to-"pigtailed" device applications.



Factory tool kits for the termination of single fibers are available.

UNILUX Series connectors are available as connector components or in complete cable assemblies. The UNILUX/FOS connector is designed to meet military-type connector specifications while in a mated condition, and will withstand an outdoor environment. The UNILUX/FOT connector is designed for controlled environments such as computer rooms and protected systems.

For complete information or a demonstration, contact our Fiber Optics Market Manager in Santa Ana, California

UNILUX FOT/FOS FEATURES

- Precision separable connectors for coupling strengthened (FOS series) and unstrengthened (FOT series) single optical fibers.
- FOS series is environmentally sealed, designed to meet military-type connector specifications in a mated condition. FOT series is for controlled environment applications.
- Precision ferrules provide high accuracy three-axis alignment for maximum optical coupling.
- Termination ferrules are available to accommodate a range of fiber diameters from 100 micrometers (.004 inch) to 325 micrometers (.013 inch) outside diameter (core plus cladding).
- Maximum relative displacement of fiber mounting hole centerlines: 12.5 micrometers (.0005 inch)
- Maximum ferrule centerline angular misalignment: 1°
- Gap: −0, +5 micrometers

FOT Ordering Information

FOT

Basic connector less ferrule

FOT-F •••

Basic ferrule assembly for UNILUX/FOT Series

Hole diameter in jewel of ferrule assembly (in micrometers)

FOS Ordering Information

FOS • - •••

Basic connector less ferrule

Connector style

- 0 = Cable receptacle, square flange mounting
- 1 = Cable receptacle, in-line, no mounting
- 2 = Box receptacle, square flange mounting for termination of device pigtails or unstrengthened fibers
- 3 = Box receptacle, jam nut mounting for termination of device pigtails or unstrengthened fibers
- 6 = Cable plug
- 7 = Cable receptacle, jam nut mounting

Cable entry

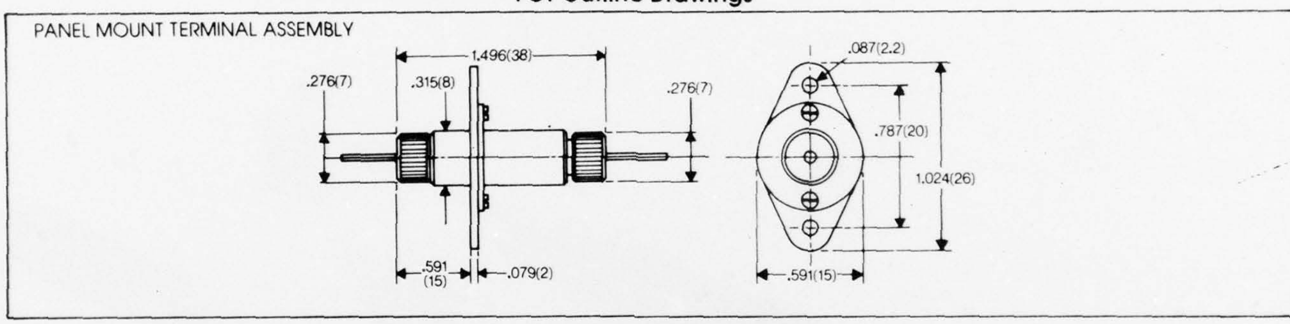
- 120 = .120" (3.05 mm) maximum cable diameter
- 160 = .160" (4.06 mm) maximum cable diameter

FOS-F •••

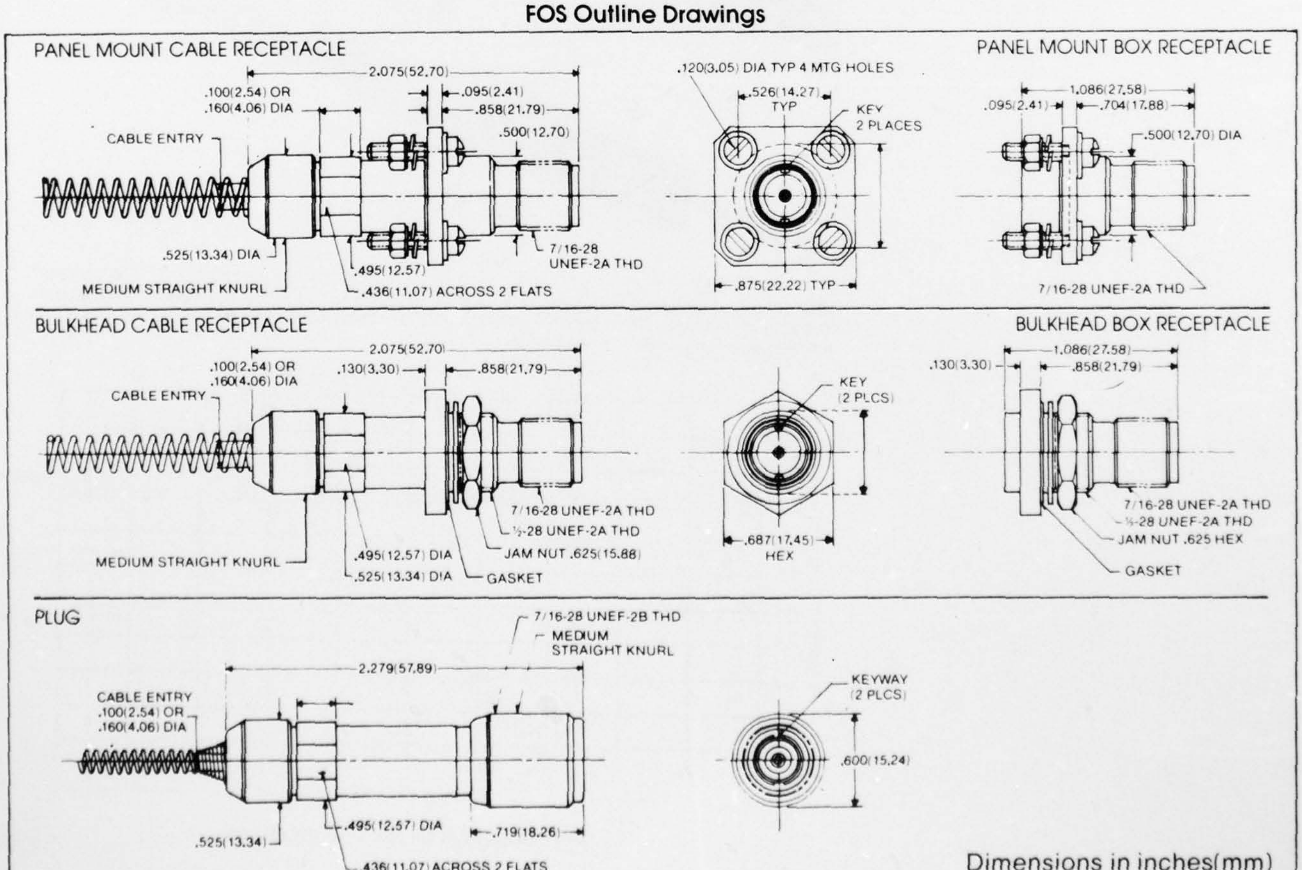
Basic ferrule assembly for UNILUX/FOS Series

Hole diameter in jewel of ferrule assembly (in micrometers)

FOT Outline Drawings



FOS Outline Drawings



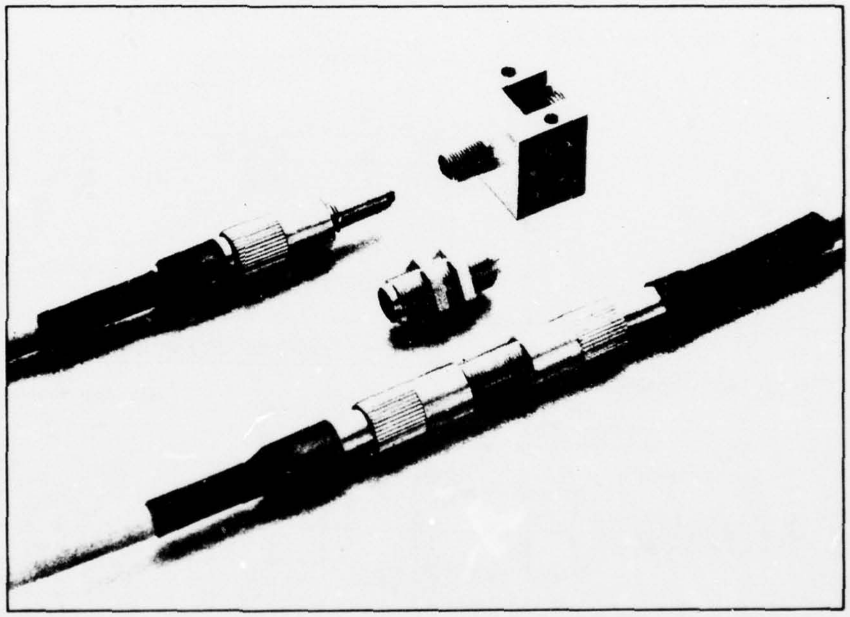
SIECOR

Siecor Optical Cables, Inc.
631 Miracle Mile
Horseheads, New York 14845
Tel: 607-739-3562
Telex: 932478
Cable: SIECOR

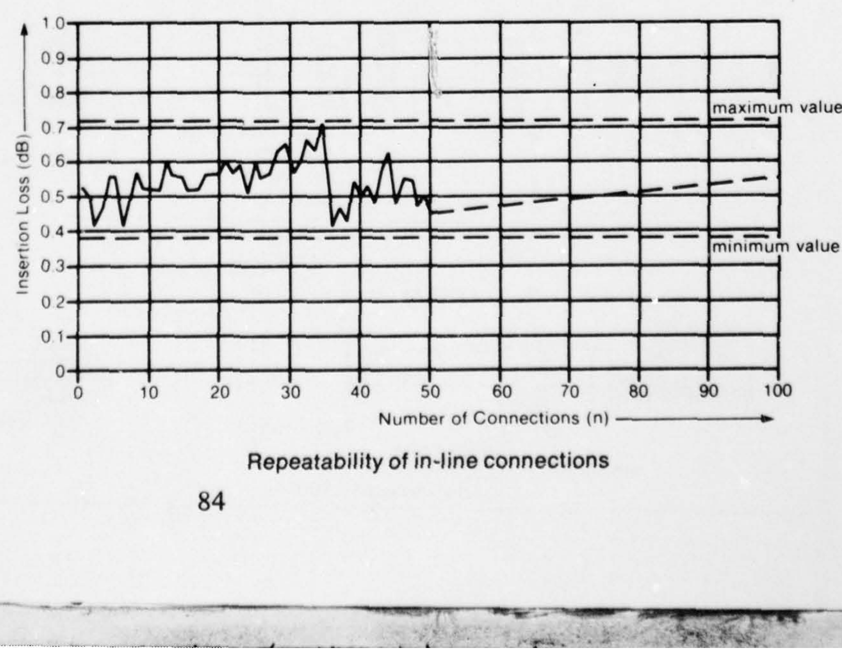
Siecor® Interconnecting Hardware and Electro-Optical Transducers for Optical Waveguide Cables

In-line connectors, terminations, and receptacles comprise the set of SIECOR® interconnecting hardware. Each element of the set mates with the others and can be interchanged with like elements supplied at other times. The hardware is compatible with SIECOR cables. (See bulletin on optical waveguide cables.)

The interchangeable hardware provides low, reproducible coupling losses upon repeated matings in normal application environments. No index matching fluid is required. Precision alignment is provided by factory assembly of the components, so that typical insertion loss of an in-line configuration is less than 1 dB.



SIECOR interconnecting hardware for optical cables. Top left, an optical cable with termination. Top right, receptacle. Right center, connecting sleeve. Bottom, two terminated cables, joined using the sleeve to form an in-line connector.



Repeatability of in-line connections